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METHODS FOR PERFORMANCE GOAL SETTING OF FIELDED JET ENGINES

by

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METHODS FOR PERFORMANCE GOAL SETTING OF FIELDED JET ENGINES

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This thesis investigates methods for constructing fielded jet engine performance goals using Non-Parametric and Parametric analysis methods. The procedures developed can be applied with any fielded jet engine. Emphasis is placed on demonstrating the use of the Naval Aviation Logistics Analysis (NALDA) database in conjunction with existing spreadsheet software programs to develop performance goals for flight hours between repairs, infant mortality rate and proper mix of scheduled/unschedulued removals. Conditional Probabilities were calculated that will assist maintenance planners in scheduling engine removals for planned maintenance.

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LIST OF ABBREVIATIONS

ANUMA	Average Number of Unscheduled Maintenance Actions
β	Beta - Weibull distribution shape parameter
CDF	Cumulative Distribution Function
ERAP	Engine Reliability Analysis Program
FOD	Foreign Object Damage
Γ	Gamma function
LMDSS	Logistics Management Decision Support System
NALDA	Naval Aviation Logistics Analysis Database
NAMO	Naval Aviation Maintenance Office
NAWCADPPE	Naval Air Warfare Center Aircraft Division Propulsion and Power Engineering
MLE	Maximum Likelihood Estimation
MTBF	Mean Time Between Failures
PDF	Probability Density Function
θ	Theta - Weibull distribution scale parameter
T/M/S	Type/Model/Series
UIC	Unit Identification Code
UMA	Unscheduled Maintenance Actions

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I. INTRODUCTION

A. BACKGROUND

1. Engine Reliability Analysis Program (ERAP)

Naval Air Warfare Center Aircraft Division Propulsion and Power Engineering (NAWCADPPE) was tasked by the Naval Air Warfare Center Aircraft Division to provide the engine community with the ability to generate, measure and report engine system performance. The ERAP provides each engine team a structured and documented process to analyze and evaluate the reliability, maintainability and availability of the engine propulsion system. The program was developed using the logic and queries stated in the Engine Reliability Analysis Program (RAP) Report Users Manual, J. Lam, February 1995, and requires data files to be obtained from the Naval Aviation Logistics Analysis (NALDA) database.

ERAP generates nine different reports which can be used to identify problem areas such as maintenance, supply, etc. The nine reports are Removal/Downgrade; Flight Hours Between Repairs;, Installed Flight Hours Between Repairs; Infant Mortality; Engine Availability; Engine Pipeline; Demand, Production and Projection; Primary Readiness Degraders/Aborts; and Primary Readiness Degraders/BCM, RPR-I/RR. This thesis will deal with three of these reports.

a. Removal/Downgrade Report

This report provides the user an option to analyze engine reliability and maintainability data by engine Type/Model/Series (T/M/S), Aircraft T/M/S, and Degree-of-Previous-Repair. It provides the user or analyst with a pictorial representation of the number of removals (unscheduled and scheduled) and downgrades (fleet and depot). This report does not take into account cannibalization because it does not require a repair. The

various charts produced can be used as indicators of system reliability, the main problem areas of the engine, how long the engines are staying in service before a repair is required, and identifying a problem with a particular level of repair. Funds can then be allocated to address these problem areas and eventually reduce the number of unscheduled engine removals and improve the repair process. (ERAP)

b. Flight Hours Between Repairs

This report provides the user or analyst an option to analyze engine reliability and maintainability data by engine T/M/S, Aircraft T/M/S, and Degree-of-Previous-Repair. This report produces charts showing the mean and median engine flight hours between repair and the number of engine removals for a specified fiscal year. The length of time engines stay on wing is an indication of the well-being of the engine and its repair process. Procedures and policies resulting in increased mean and median time between repair have increased the overall product reliability. (ERAP)

c. Infant Mortality

This report provides the user or analyst an option to analyze engine reliability and maintainability data by engine T/M/S, Aircraft T/M/S, and Degree-of-Previous-Repair. Interest is centered on engines removed with low Flight-Hours-Since-Repair which is the mortality threshold. This threshold is a user input variable based on the average engine operating hours. (ERAP)

2. Naval Aviation Logistics Data Analysis (NALDA)

The NALDA system evolved from a need for data analysis capabilities to support growth in sophistication and complexity of naval associated support systems. Its primary objective is to utilize" state of the art" data systems technology to provide centralized

logistics data analysis capabilities.

Currently, NALDA is an operational Automated Information System. Computer services are provided by the Defense Megacenter Mechanicsburg, PA via a service level agreement. The system was developed utilizing the Data Base Management System 2000. The telecommunications network presently consists principally of dial-up and WATS lines. Data input is provided from the Naval Aviation Maintenance and Management Data System (Aviation 3M) via the Naval Sea Logistics Center, Aviation Support Office and the Naval Air Technical Services Facility.

The NALDA System provides a centralized data bank, including maintenance retrieval capabilities that can be used in an interactive or batch manner through remote terminals in the Naval Aviation Integrated Logistics Support community. Both the content of the data retrieval and analysis capabilities are designed to assist users in making improvements in fleet aircraft readiness. NALDA's capabilities furnish a wide spectrum of uses for managers, engineers, and analysts utilizing the system. All uses are related to answering questions that arise with regard to day-to-day logistics problems. The system has the ability to access data files interactively on demand. Another aspect is the on-line availability of special programs (deterministic models, regression analysis) to predict the effects of actions or casual relationships. For this second set of uses, NALDA provides the database, and a storage place for separately developed, special application programs needed for analysis.

The NALDA data base is currently set up as a hierarchly data base that is not user friendly and is unwieldly to use. It takes many hours of training and experience to learn how to write a query properly so as to extract needed information. A new system is under development to make the access to the NALDA data base more user friendly. It is called the Logistics Management Decision Support System (LMDSS). LMDSS is a flat file relational data base that will use a graphic user interface for access to the data base. LMDSS will make it easier to query the data base, there will be more flexibility in the type of queries, and the logistic support managers will be able to relate the information easier

and more effectively. Access to this system will be available through the Navy Wide Area Network.

B. RESEARCH QUESTIONS

The overall guiding questions are as follows:

- What methods and criteria can be used effectively for establishing an operational jet engine goal for mean flight hours between repair and expected number of unscheduled removals during a given report period that can be integrated with the ERAP Removal and Downgrade Report.
- What methods and criteria can be used effectively for establishing operational jet engine goal for infant mortality. Specifically what flight hour interval is infant mortality and what are potential actions for reducing it..
- What impact does engine removals for cannibalization and engine removals by direction have on engine flight hours between repair.

C. TWO METHODS OF DATA ANALYSIS

The time-between failure data in the five-year data base used in this thesis was analyzed in two distinct ways. One method made no assumption about the probability distribution of the time between failures of the engines. All inferences are drawn from the raw data itself using non-parametric statistics. Inferences and performance measures derived using this method are not susceptible to criticism about statistical properties relevant to an assumed probability distribution. However this method of analysis is not as readily useful in some types of advanced analysis. Consequently a parametric analysis was also performed using the Weibull distribution to fit the basic data base. This analysis was applied to each modified data base for which non-parametric performance parameters were computed. Details of both these two general methods are provided in Chapter II.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The scope of the research was limited to the TF-34 engine as a case example because it is used as the model for the development of the ERAP. A query of the NALDA database was conducted to give a list of all engine removals covering fiscal years 90 through 94. This gave a five year history of removal transactions for any reason which the author considered as providing significant data points for analysis. Some data points were deleted due to inaccurate or missing information. They were considered insignificant in the final analysis.

The author assumed the readers understanding of basic statistics, familiarity with NALDA System, ERAP, and experience with spreadsheet software programs. The spreadsheet software used in this thesis for data analysis was Microsoft Excel Version 5.0.

E. THESIS PREVIEW

A recurring need of integrated logistics support managers and engine type commanders; Naval Aviation Depots, Naval Aviation Maintenance Office, and Naval Air Systems Command Headquarters is to define problem areas, the magnitude of the problem, isolate the problem to the functional/organizational level and formulate and implement a solution. All problem areas can be identified to one of the areas encompassed by the scope of integrated logistics support: maintenance, support personnel, support equipment, operations, facilities, etc.

In order to meet the need of the logistic support community, the Navy currently collects data on all jet engines. The data collection is done through the use of programs such as the Maintenance Data System, Naval Aviation Logistics Command Information System, Depot Maintenance Data System, Technical Directive Status Accounting System, Master Index of Repairables, Engine Composite and Tracking, and the Naval Flight Information Record. (Lucas, 1994)

The data for these sources of logistics information are collected from all three levels of maintenance; namely organizational, intermediate and depot. The recording of daily maintenance and management data is very thorough and detailed. It includes such information as work unit code, type of maintenance code, serial numbers, hours, reason for removal, unit identification codes, status codes and other information. This information is eventually compiled and transmitted to the NAMO. Access to the data is available to researchers, managers and end users through the NALDA System. (Lucas, 1994)

An analyst at NAWCADPPE, J. Lam, provided the data file copy of all engine removals for fiscal years 90 through 94. Through the use of a spreadsheet software program, the data was imported and non-failure related data was filtered out. That left 723 records of engines that had been removed for failure reasons. This data was then analyzed using both non-parametric and parametric statistical analysis procedures. These procedures provided the engine mean-time-between-failure (MTBF), standard deviation, the reliability function, and the failure rate function.. The analysis also provides the conditional reliability function in which the probability that an engine will live to a given future time, such as a scheduled removal time, given it has accumulated a given amount of flight hours since the last repair.

While filtering the data for non-failure removal reasons, it became apparent that there was a correlation between an engine removal for cannibalization or by direction and the length of time before the next failure. An analysis of the data was conducted to calculate the number of instances where a cannibalization or directed removal was followed by a failure and the number of flight hours before failure. A statistical analysis was conducted which allowed the determination of the mean, standard deviation, and median of these failue times. This information was then evaluated for comparison with and impact on the mean engine flight hours between repairs for the five-year population of engines.

II. STATISTICAL ANALYSIS OF ENGINE FAILURE DATA

A. FILTERING NALDA ENGINE REMOVAL DATA

The following discussion outlines the procedures for filtering the engine removal data that is received from the query of the NALDA System. This filtering is necessary so as to ensure all the failure data is captured and logical decisions can be made on what to keep for statistical analysis. This systematic approach can be applied to any engine T/M/S:

Step 1: Query the NALDA database for data on all engine removals for any reason, listing engine serial number, flight hours since new, flight hours since last repair, removal UIC, status/star code, removal reason code, degree prior repair, and prior removal reason. All these fields are needed so logical decisions can be made on pertinent data that needs to be kept. There were 1812 entries from this query.

Step 2: Decode the data if necessary, and import it into any spreadsheet software program. Graphics and statistical capabilities are required. Appendix D discusses the spreadsheet procedures used in manipulating the data base and making all calculations.

Step 3: Delete the entries that are reporting removal for non-failure reasons. The codes and number of entries deleted from the data used for this thesis are given in Table 1.

Removal Code	Removal Description	Number of Entries
3E	Faulty Handling/Dropped	2
3W	Removal for Cannibalization	579
4B	Accident/Incident Damage	9
4D	Directed Removal	198
4L	Damaged in Transit	1
5G	High Time	15
6A	Mod/TDC inc	16
7C	High Time Component	225
7D	High Time Engine (only)	21

Table 1. Deleted Entries from Initial Data Query

There were nine duplicate entries, six entries missing data, and one entry with a bad removal code. Seven entries that were related to the 50 new engines was also deleted. The final results of editing the data are in Appendix A and includes 723 records. The data is now ready to be analyzed using either non-parametric or parametric methods.

B. NON-PARAMETRIC METHODS AND ANALYSIS

The five-year data base was screened to obtain 723 operating times between engine failures. An engine failure initiates an unscheduled maintenance action. Engines may be removed from operation without having failed for other reasons; e.g., Directed Removal and Cannibalization. These failure times were arranged in ascending order, from smallest to largest. This arrangement of failure times together with the index (rank) of each time establishes the non-parametric probability distribution of the time-between-failures for this population of engines for the five-year period. This probability distribution

can be used to compute MTBF, reliability values for given operating times, and the proportion of engines with t accumulated operating hours since last failure that will not fail prior to the next scheduled maintenance which occurs at T_0 operating hours.

Appendix B, Basic Five-Year Time Between Failure Data Base, displays the ordered failure times and their assorted ranks. The time range of this distribution is (0,2128). Let N_j denote the number of recorded failure times that equal j hours in Appendix B. For example $N_8 = 0$, $N_{44} = 1$, $N_{89} = 2$, etc. Then the probability that an engine failure occurs at time j is N_j / 723. Consequently the mean of this probability distribution, MTBF, is

$$MTBF = \frac{\sum_{j=0}^{2128} jN_j}{723} \tag{1}$$

$$= \frac{\sum_{i=1}^{723} T_i}{723} = \frac{346802}{723} = 479.67$$

where $T_1, T_2, \ldots, T_{723}$ are the recorded failure times in Appendix B.

The Median Time Between Failures, P_{50}, is the 50^{th} percentile of this distribution and is

$$P_{50} = \frac{T_{362} + T_{361}}{2} = \frac{384 + 384}{2} = 384 \tag{2}$$

because (723 + 1) / 2 = 362 and (723 - 1) / 2 = 361. This means that 50% of the failure times occur before 384 hours of operation.

The probability that an engine selected at random will fail before operating t hours since last repair is, F(t), the ratio of the index (rank), i(t), for that time t divided by 723. That is, if T denotes operating time to failure since last repair of a randomly selected engine, then

$$F(t) = P(T \leq t) = \frac{i(t)}{723} = \frac{number\ of\ engines\ failed\ \leq t}{total\ number\ of\ engines} \tag{3}$$

F(t) is the cumulative distribution function (CDF). Computed values of F(t) is presented in Table 2 and a graph of F(t) is presented in Figure 1.

Similarly, the reliability function is

$$R(t) = P(T > t) = \frac{723 - i(t)}{723} \tag{4}$$

which simplifies to 1-F(t). The data for R(t) is presented in Table 2 and a graph of R(t) is presented in Figure 1.

The conditional probability $R(T_0 \mid t_0)$ that an engine which has accumulated t_0 operating hours since last failure will not fail before it has accumulated a total of T_0 operating hours, $(T_0 > t_0)$, is

$$R(T_0|t_0) = P(T>T_0|T>t_0) = \frac{P(T>T_0)}{P(T>t_0)} \tag{5}$$

$$= \frac{723 - i(T_0)}{723} \div \frac{723 - i(t_0)}{723}$$

$$= \frac{723 - i(T_0)}{723 - i(t_0)}$$

Some of these conditional probabilities for selected values of t_0 and T_0 are presented in Table 3 and graphically represented in Figure 2. For example in Table 2,

Failure Hrs t	Index Number i(t)	Reliability R(t)	CDF F(t)
50	124	0.828	0.172
100	172	0.762	0.238
150	197	0.728	0.272
200	229	0.683	0.317
250	275	0.620	0.380
300	305	0.578	0.422
350	340	0.530	0.470
400	376	0.480	0.520
450	407	0.437	0.563
500	440	0.391	0.609
550	462	0.361	0.639
600	487	0.326	0.674
650	503	0.304	0.696
700	526	0.272	0.728
750	541	0.252	0.748
800	555	0.232	0.768
850	571	0.210	0.790
900	590	0.184	0.816
950	605	0.163	0.837
1000	620	0.142	0.858
1050	633	0.124	0.876
1100	644	0.109	0.891
1150	657	0.091	0.909
1200	673	0.069	0.931
1250	679	0.061	0.939
1300	685	0.053	0.947
1350	689	0.047	0.953
1400	701	0.030	0.970
1450	708	0.021	0.979
1500	714	0.012	0.988
1550	716	0.010	0.990
1600	718	0.007	0.993
1650	721	0.003	0.997
1700	721	0.003	0.997
1750	721	0.003	0.997
1800	721	0.003	0.997
1850	721	0.003	0.997
1900	721	0.003	0.997
1950	722	0.001	0.999
2000	722	0.001	0.999

MTBF	479.67
Std Dev	420.53
Median	384

Table 2. Non-parametric Statistical Functions Data
(All failure times)

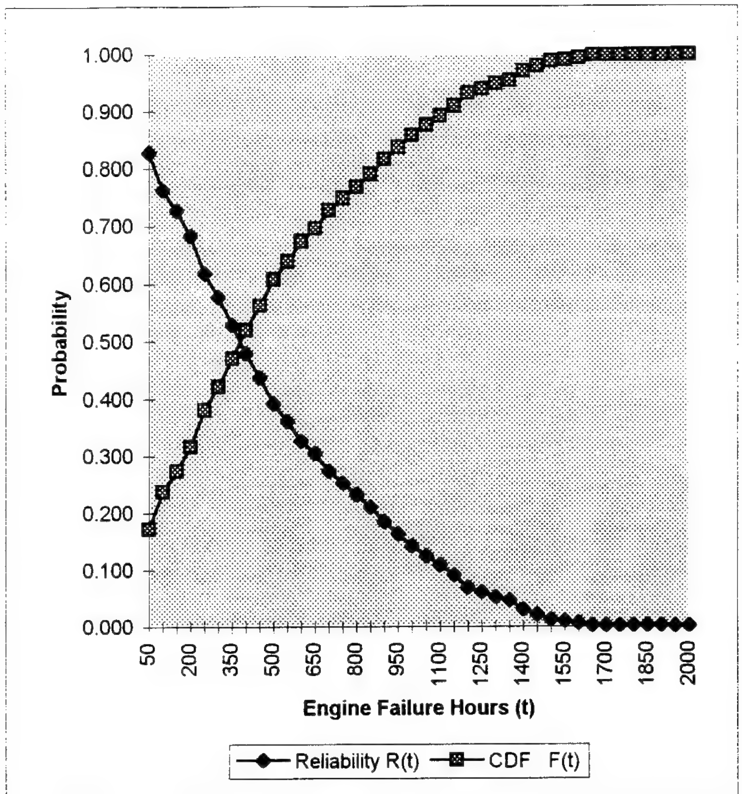
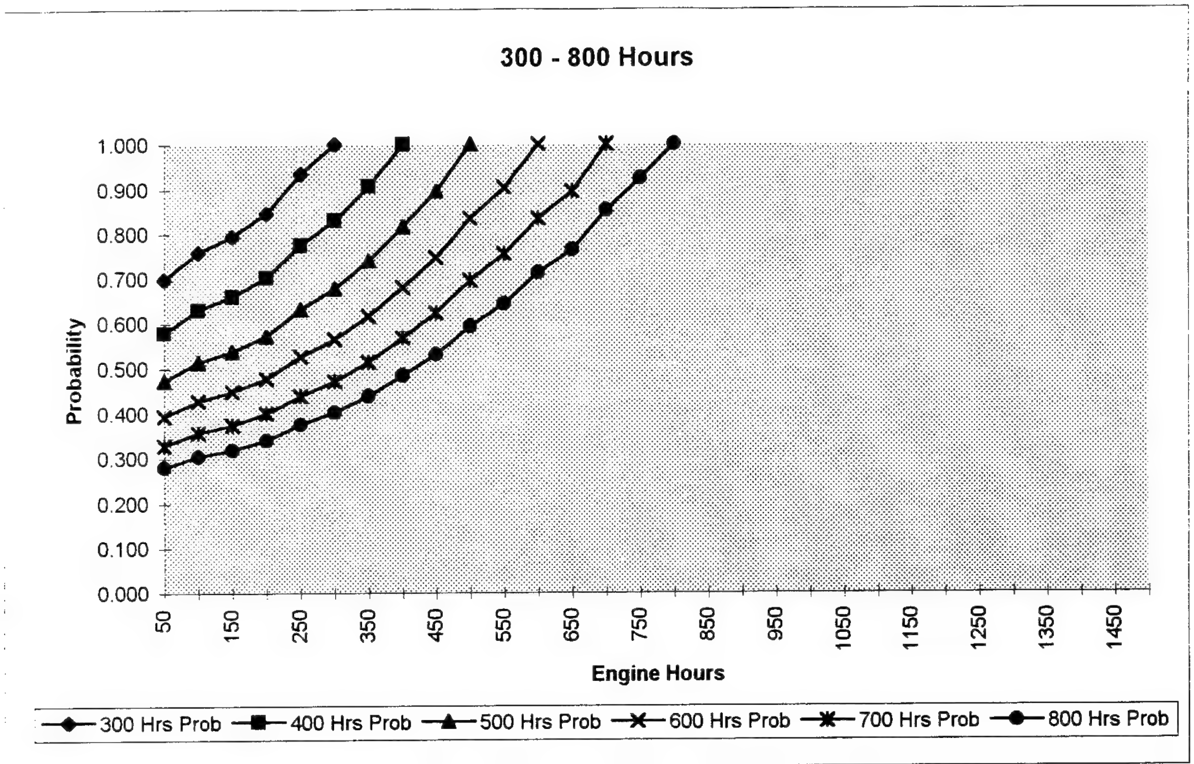


Figure 1. Non-parametric Statistical Functions Curves
(All failure times)

FHRPR	Index	300 Hrs	400 Hrs	500 Hrs	600 Hrs	700 Hrs	800 Hrs	900 Hrs	1000 Hrs	1100 Hrs	1200 Hrs	1300 Hrs	1400 Hrs	1500 Hrs
	Number	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob	Prob
50	124	0.698	0.579	0.472	0.394	0.329	0.280	0.222	0.172	0.132	0.083	0.063	0.037	0.015
100	172	0.759	0.630	0.514	0.428	0.358	0.305	0.241	0.187	0.143	0.091	0.069	0.040	0.016
150	197	0.795	0.660	0.538	0.449	0.375	0.319	0.253	0.196	0.150	0.095	0.072	0.042	0.017
200	229	0.846	0.702	0.573	0.478	0.399	0.340	0.269	0.209	0.160	0.101	0.077	0.045	0.018
250	275	0.933	0.775	0.632	0.527	0.440	0.375	0.297	0.230	0.176	0.112	0.085	0.049	0.020
300	305	1.000	0.830	0.677	0.565	0.471	0.402	0.318	0.246	0.189	0.120	0.091	0.053	0.022
350	340		0.906	0.739	0.616	0.514	0.439	0.347	0.269	0.206	0.131	0.099	0.057	0.023
400	376		1.000	0.816	0.680	0.568	0.484	0.383	0.297	0.228	0.144	0.110	0.063	0.026
450	407			0.896	0.747	0.623	0.532	0.421	0.326	0.250	0.158	0.120	0.070	0.028
500	440			1.000	0.834	0.696	0.594	0.470	0.364	0.279	0.177	0.134	0.078	0.032
550	462				0.904	0.755	0.644	0.510	0.395	0.303	0.192	0.146	0.084	0.034
600	487				1.000	0.835	0.712	0.564	0.436	0.335	0.212	0.161	0.093	0.038
650	503					0.895	0.764	0.605	0.468	0.359	0.227	0.173	0.100	0.041
700	526					1.000	0.853	0.675	0.523	0.401	0.254	0.193	0.112	0.046
750	541						0.923	0.731	0.566	0.434	0.275	0.209	0.121	0.049
800	555						1.000	0.792	0.613	0.470	0.298	0.226	0.131	0.054
850	571							0.875	0.678	0.520	0.329	0.250	0.145	0.059
900	590							1.000	0.774	0.594	0.376	0.286	0.165	0.068
950	605								0.873	0.669	0.424	0.322	0.186	0.076
1000	620								1.000	0.767	0.485	0.369	0.214	0.087
1050	633									0.878	0.556	0.422	0.244	0.100
1100	644									1.000	0.633	0.481	0.278	0.114
1150	657										0.758	0.576	0.333	0.136
1200	673										1.000	0.760	0.440	0.180
1250	679											0.864	0.500	0.205
1300	685											1.000	0.579	0.237
1350	689												0.647	0.265
1400	701												1.000	0.409
1450	708													0.600
1500	714													1.000

Table 3. Non-parametric Conditional Probability



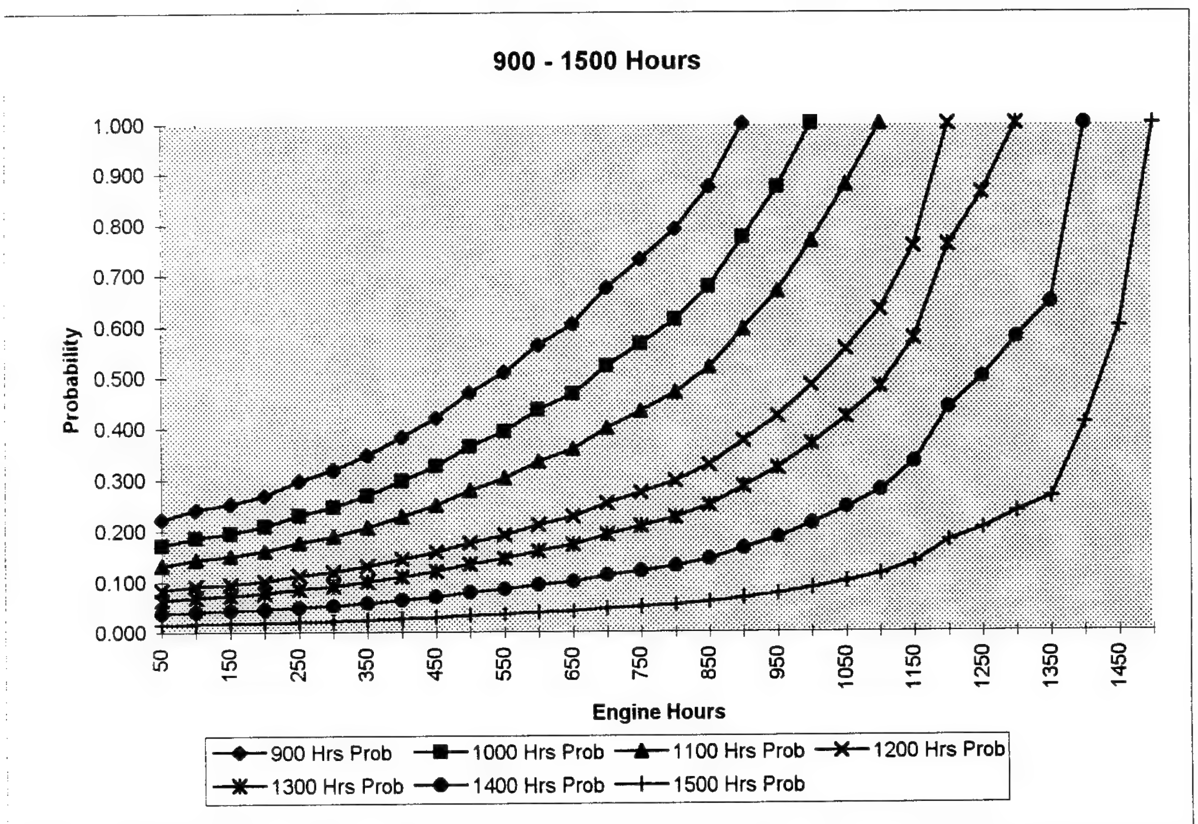


Figure 2. Non-parametric Conditional Probability Curves

R(500|50) = 0.472. This means that 47.2% of the engines which have accumulated 50 hours of operating time will continue to operate without failure to time 500 hours.

It may be desirable to remove some of the data points from the basic data set in Appendix A so that related statistical measures could be made for the modified database. This would yield a different arrangement of indices (ranks) with failure times. The concepts defined above would also apply to the new data base; i.e., to the new probability distribution that results from removing failure times. If N denotes the number of data elements in the new data base then

$$MTBF = \frac{\sum_{1}^{N} T_i'}{N} \tag{6}$$

$$F(t) = \frac{i'(t)}{N} \tag{7}$$

$$R(t) = \frac{N - i'(t)}{N} \tag{8}$$

$$R(T_0|t_0) = \frac{N - i'(T_0)}{N - i'(t_0)} \tag{9}$$

where i'(t) is the index (rank) of time t in the new data base and T_i' are the failure times in the new data base.

It is important to note that if the basic data base is modified by removing only failure times whose value is less than t_0 then the conditional probability $R(T_0|t_0)$ in Equation 9 is the same as that in equation 5. That is , if K failure times are removed from the data base, then in Equation 9, N=723-K, $i'(T_0)=(T_0)-K$ and $i'(t_0)=i(t_0)-K$. Consequently

Table 3 will still apply for all times t_0 and T_0 that are greater than the largest failure time deleted in a modified data base.

The conditional probability function $R(T_0|t_0)$ can be used to determine what sections of the data base (small failure times, intermediate failure times, large failure times) have a wear-in feature, what sections have no-wear-out feature and what sections have wear-out feature. These features are related to $R(T_0|t_0)$ and $R(t_0)$ as follows:

Wear-in: $R(t+h|t) > R(h)$

No-wear-out: $R(t+h|t) = R(h)$

Wear-out: $R(t+h|t) < R(h)$

Using Table 2 and Table 3, the following computations are readily derived

For $h = 50$: $R(50) = .828$

$R(100|50) = .762/.828 = .920 > R(50)$

$R(150|100) = .728/.762 = .955 > R(50)$

$R(200|150) = .683/.728 = .938 > R(50)$

$R(1000|950) = .142/.163 = .871 > R(50)$

For $h = 100$: $R(100) = .762$

$R(200|100) = .683/.762 = .896 > R(100)$

$R(300|200) = .578/.683 = .846 > R(100)$

$R(400|300) = .480/.578 = .830 > R(100)$

$R(700|600) = .272/.326 = .838 > R(100)$

$R(1000|900) = .142/.184 = .774 > R(100)$

$R(1100|1000) = .109/.142 = .767 \cong R(100)$

$R(1200|1100) = .069/.109 = .633 < R(100)$

For $h = 200$: $R(200) = .683$

$R(400|200) = .480/.683 = .702 > R(200)$

$R(600|400) = .326/.480 = .680 \cong R(200)$

$R(800|600) = .232/.326 = .712 > R(200)$

$R(1000|800) = .142/.232 = .613 < R(200)$

$R(1200|1000) = .069/.142 = .485 < R(200)$

For h = 400: $R(400) = .480$

$R(800|400) = .232/.480 = .484 \cong R(400)$

$R(900|500) = .184/.391 = .470 < R(400)$

$R(1000|600) = .142/.326 = .436 < R(400)$

$R(1100|700) = .109/.272 = .401 < R(400)$

It is useful to note that if

$R(t+h|t) > R(h)$, then

$1 - R(t+h|t) < 1 - R(h)$ or

P(fails in next h hours|alive at t) < P(fails in first h hours)

The above calculations support the following conclusions:

- The segment of the basic data base with small failure times ($\leq$ 100) has a wear-in feature. The data suggests that engines that are alive at time t are more likely to live an additional t hours than they were to live the first t hours since repair. This suggests a problem with the state of engines that are being returned to the fleet.

- The segment of engines with failure times between 100 and 200 hours has a moderate wear-in feature. The data suggests that engines that have not failed up to 200 hours are more likely to live an additional 200 hours than the likelihood of freshly reintroduced engines surviving their first 200 hours.

- Engines that have failure times between 200 and 400 hours have little wear-out. That is they are about as likely to live beyond twice their current age as they were to live to their current age since last repair.

- Some wear-out in the engines begins to take place around 400 hours and accelerates as time accumulates on the engines.

Table 4 shows the statistical functional data after removing all the zero failure times and is graphically represented in Figure 3. Table 5 shows the statistical functional data after removing the first 10% of the failure times and is graphically represented in Figure 4.

Failure Hrs t	Index Number i(t)	Reliability R(t)	CDF F(t)
50	85	0.876	0.124
100	133	0.806	0.194
150	157	0.770	0.230
200	190	0.722	0.278
250	236	0.655	0.345
300	266	0.611	0.389
350	301	0.560	0.440
400	337	0.507	0.493
450	368	0.462	0.538
500	401	0.414	0.586
550	423	0.382	0.618
600	448	0.345	0.655
650	464	0.322	0.678
700	487	0.288	0.712
750	502	0.266	0.734
800	516	0.246	0.754
850	532	0.222	0.778
900	551	0.194	0.806
950	566	0.173	0.827
1000	581	0.151	0.849
1050	594	0.132	0.868
1100	605	0.115	0.885
1150	618	0.096	0.904
1200	634	0.073	0.927
1250	640	0.064	0.936
1300	646	0.056	0.944
1350	650	0.050	0.950
1400	662	0.032	0.968
1450	669	0.022	0.978
1500	675	0.013	0.987
1550	677	0.010	0.990
1600	679	0.007	0.993
1650	682	0.003	0.997
1700	682	0.003	0.997
1750	682	0.003	0.997
1800	682	0.003	0.997
1850	682	0.003	0.997
1900	682	0.003	0.997
1950	683	0.001	0.999
2000	683	0.001	0.999

MTBF	507.02
Std Dev	416.00
Median	405

Table 4. Non-parametric Statistical Functions Data
(Less zero failure times)

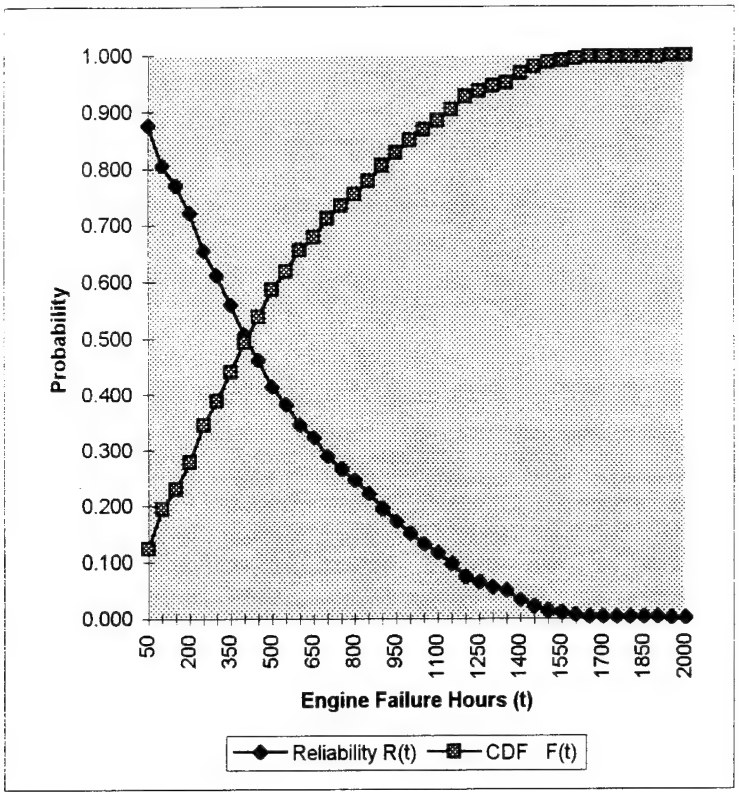


Figure 3. Non-parametric Statistical Functions Curves
(Less zero failure times)

Failure Hrs t	Index Number i(t)	Reliability R(t)	CDF F(t)
50	52	0.920	0.080
100	100	0.846	0.154
150	124	0.810	0.190
200	157	0.759	0.241
250	203	0.688	0.312
300	233	0.642	0.358
350	268	0.588	0.412
400	304	0.533	0.467
450	335	0.485	0.515
500	368	0.435	0.565
550	390	0.401	0.599
600	415	0.363	0.637
650	431	0.338	0.662
700	454	0.303	0.697
750	469	0.280	0.720
800	483	0.258	0.742
850	499	0.233	0.767
900	518	0.204	0.796
950	533	0.181	0.819
1000	549	0.157	0.843
1050	561	0.138	0.862
1100	572	0.121	0.879
1150	585	0.101	0.899
1200	601	0.077	0.923
1250	607	0.068	0.932
1300	613	0.058	0.942
1350	617	0.052	0.948
1400	629	0.034	0.966
1450	636	0.023	0.977
1500	642	0.014	0.986
1550	644	0.011	0.989
1600	646	0.008	0.992
1650	646	0.008	0.992
1700	649	0.003	0.997
1750	649	0.003	0.997
1800	649	0.003	0.997
1850	649	0.003	0.997
1900	649	0.003	0.997
1950	650	0.002	0.998
2000	650	0.002	0.998

MTBF	532.54
Std Dev	410.27
Median	428

Table 5. Non-parametric Statistical Functions Data
(Less first 10% of failure times)

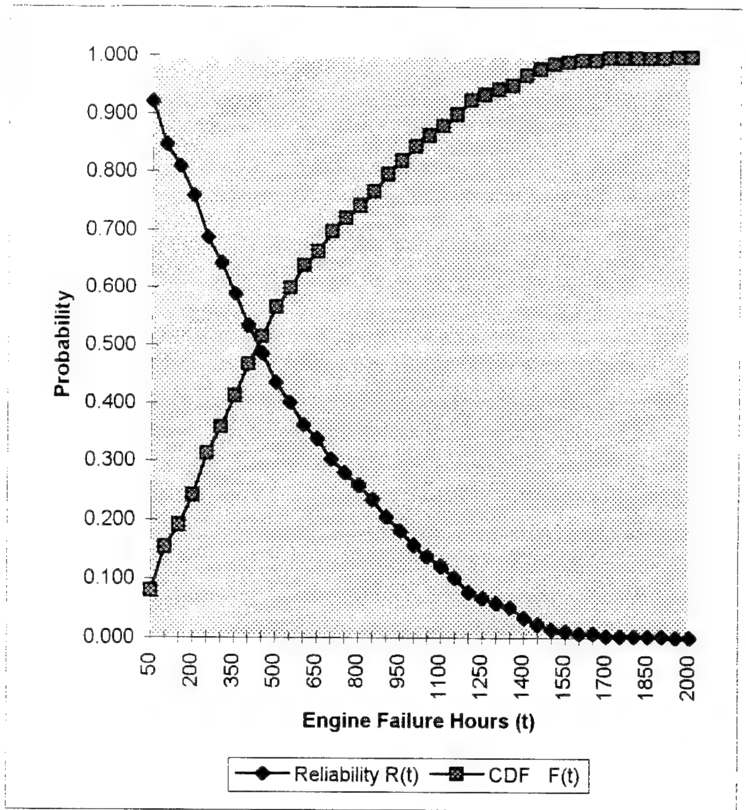


Figure 4. Non-parametric Statistical Function Curves
(Less first 10% of failure times)

C. PARAMETRIC METHODS AND ANALYSIS USING THE WEIBULL DISTRIBUTION

Computing the statistical measures defined in Equations 1 - 9 in Chapter II Section B requires referral to the five-year data base or a set of charts or figures. An alternative approach is to fit a Weibull distribution to the five-year data base to obtain estimates of the two parameters in the Weibull distribution. This would allow the development of closed form expressions equations for the four statistical measures in Equations 6 - 9 of Chapter II Section B. It would also allow the development of equations for more comprehensive concepts such as an optimum minimum maintenance time, T_0, for an engine with t_0 hours of operating time accounting for several cost factors. This approach will more likely allow existing cost effectiveness models to be used to develop some optimal maintenance policy characteristics.

The Weibull distribution can be used to model the distribution of failure times for a device that has wearout or wearin or neither. That is, devices whose failure rate function is increasing in time (wear-out) or decreasing in time (wear-in) or constant (no-wear-out). In this section, a method for fitting the Weibull distribution to the five-year data base is described.

If the time to failure, T, of an engine has probability density function f(t) and reliability function R(t), R(t) = P(T>t), then its failure rate function, h(t) is

$$h(t) = \frac{f(t)}{R(t)} \tag{10}$$

If T has the exponential distribution, then

$$f(t) = \frac{1}{\theta} \exp^{-\frac{t}{\theta}} \quad , \quad t>0 \tag{11}$$

$$R(t) = \exp^{-\frac{t}{\theta}} \tag{12}$$

$$h(t) = \frac{1}{\theta} \equiv \lambda \tag{13}$$

$$MTBF = E(T) = \theta = \frac{1}{\lambda} \tag{14}$$

$$Variance\ \ of\ \ T\ \ is\ \ Var(T) = \theta^2 \tag{15}$$

$$Standard\ \ deviation\ \ of\ \ T\ \ is\ \ \sigma_T = \sqrt{Var(T)} = \theta \tag{16}$$

The exponential distribution is the only continuous distribution for which h(t) is constant. It is also the only distribution for which the mean is the reciprocal of the failure rate. The exponential distribution is a special case of the Weibull distribution which is shown later in this section. It is important to realize that assuming the exponential distribution is an appropriate distribution to model the time to failure of engines coming out of a repair scenario, carries implications about little or no effective wearout in the engines for a large proportion of the population. This means that given an engine has not failed in the first t hours of operation since last repair, it is just as likely not to fail in the next t hours as it was not to fail in the first t hours since last repair. The five-year data base does not support this no-wearout feature for engines that have accumulated 400 or more hours.

If time to failure, T, has a Weibull distribution with scale parameter θ and shape parameter β we write T is $W(\theta, \beta)$. Its density function f(t), reliability function, R(t), and failure rate function, h(t), respectively, are

$$f(t) = \beta \left(\frac{1}{\theta}\right)^{\beta} t^{\beta-1} \exp^{-\left(\frac{t}{\theta}\right)^{\beta}} \qquad t > 0\ ,\ \theta > 0\ ,\ \beta > 0 \tag{17}$$

$$R(t) = \exp^{-(\frac{t}{\theta})^{\beta}} \tag{18}$$

$$h(t) = \beta(\frac{1}{\theta})^{\beta}\ t^{\beta-1} \tag{19}$$

$$F(t) = 1 - R(t) \tag{20}$$

$$MTBF = \theta\Gamma(1 + \frac{1}{\beta}) \tag{21}$$

$$Variance\ \ (T^{\beta}) = \theta^{2}\ [\ \Gamma(1 + \frac{2}{\beta}) - \Gamma^{2}(1 + \frac{1}{\beta})] \tag{22}$$

where $\Gamma(x)$ is the gamma function for which established tables are included in Appendix D.

If $\beta<1$, the population of engines have a wear-in feature. If $\beta=1$, the distribution is exponential. If $\beta>1$, the population of engines have a wear-out feature.

An important relation between the Weibull and exponential distributions is the following:

If T has a $W(\theta,\beta)$ distribution then T^{β} has an exponential distribution with mean θ^{β}. Therefore

$$E(T^{\beta}) = \sqrt{Var\ \ T^{\beta}} = \theta^{\beta} \tag{23}$$

because the mean and standard deviation of the exponential distribution are equal. This property is used to fit a Weibull distribution to the five-year data base.

The most difficult part of fitting a distribution to a set of data is to fit the tails of the distribution. To do this well, usually requires some modifications to standard statistical curve-fitting procedures.

The Maximum Likelihood Estimation (MLE) Method is one way of fitting a Weibull distribution to the five-year data base. The MLE method assumes that all of the engines have the same failure time distribution. This is not likely to be the case in this population of engines because each failed engine is not restored to the same quality level of operating condition before it is declared ready for operation. They have components of different ages determined by numerous factors. This population of engines has peculiar failure patterns for small failure times. For example there are numerous failure times equal to zero in the basic data base.

The following procedure was used to fit a $W(\theta,\beta)$ distribution to the five-year data base. If the failure time T is $W(\theta,\beta)$ then T^{β} has an exponential distribution with mean θ^{β} and from equation (23) the estimates of θ^{β} and $\sqrt{\mathrm{Var}\ T^{\beta}}$ should be nearly equal. That is

$$\frac{\Sigma T_i^{\beta}}{N} = [\frac{1}{N-1}\ ((\Sigma T_i^{2\beta}) - \frac{(\Sigma T_i^{\beta})^2}{N})]^{0.5} \qquad (24)$$

$$i.e. \quad \frac{\Sigma T_i^{\beta}}{723} = [\frac{1}{722}\ ((\Sigma T_i^{2\beta}) - \frac{(\Sigma T_i^{\beta})^2}{723})]^{0.5}$$

where the index runs from 1 to 723 on all three summation symbols. This equation is solved by iteration for β. This gives an estimate, β(hat), of β.

The estimate, θ(hat), for θ is obtained using estimates for parameters in the equation

$$E(T^{\beta}) = \theta^{\beta} \tag{25}$$

$$i.e. \quad \left(\frac{\Sigma T_i^{\hat{\beta}}}{723}\right)^{1/\hat{\beta}} = \hat{\theta}$$

After completion of determining θ(hat) and β(hat), then substitution can be made into equations (17) through (21) and the distribution functions can be determined. Computed values for the Weibull distribution statistical functions are presented in Table 6 and the graphs of these functions are presented in Figures 5 through 8.

The conditional probability $R(T_0|t_0)$ that an engine which has accumulated t_0 operating hours since last failure will not fail before it has accumulated a total of T_0, $(T_0 > t_0)$, operating hours is

$$P(T>T_0 | T>t_0) = \frac{P(T>T_0)}{P(T>t_0)} \tag{26}$$

$$= \frac{\exp^{-\left(\frac{T_0}{\hat{\theta}}\right)^{\hat{\beta}}}}{\exp^{-\left(\frac{t_0}{\hat{\theta}}\right)^{\hat{\beta}}}}$$

$$= \exp^{-\left[\left(\frac{T_0}{\hat{\theta}}\right)^{\hat{\beta}} - \left(\frac{t_0}{\hat{\theta}}\right)^{\hat{\beta}}\right]}$$

Failure Times t	Weibull PDF f(t)	Weibull CDF F(t)	Failure Rate h(t)	Reliability R(t)
50	0.0013	0.0570	0.0014	0.9430
100	0.0014	0.1271	0.0016	0.8729
150	0.0014	0.1993	0.0018	0.8007
200	0.0014	0.2702	0.0019	0.7298
250	0.0013	0.3382	0.0020	0.6618
300	0.0012	0.4024	0.0021	0.5976
350	0.0012	0.4624	0.0021	0.5376
400	0.0011	0.5179	0.0022	0.4821
450	0.0010	0.5690	0.0023	0.4310
500	0.0009	0.6157	0.0023	0.3843
550	0.0008	0.6581	0.0024	0.3419
600	0.0007	0.6966	0.0024	0.3034
650	0.0007	0.7313	0.0025	0.2687
700	0.0006	0.7626	0.0025	0.2374
750	0.0005	0.7905	0.0025	0.2095
800	0.0005	0.8156	0.0026	0.1844
850	0.0004	0.8379	0.0026	0.1621
900	0.0004	0.8577	0.0026	0.1423
950	0.0003	0.8753	0.0027	0.1247
1000	0.0003	0.8909	0.0027	0.1091
1050	0.0003	0.9047	0.0027	0.0953
1100	0.0002	0.9168	0.0027	0.0832
1150	0.0002	0.9275	0.0028	0.0725
1200	0.0002	0.9369	0.0028	0.0631
1250	0.0002	0.9452	0.0028	0.0548
1300	0.0001	0.9524	0.0028	0.0476
1350	0.0001	0.9587	0.0029	0.0413
1400	0.0001	0.9642	0.0029	0.0358
1450	0.0001	0.9691	0.0029	0.0309
1500	0.0001	0.9733	0.0029	0.0267
1550	0.0001	0.9769	0.0029	0.0231
1600	0.0001	0.9801	0.0030	0.0199
1650	0.0001	0.9828	0.0030	0.0172
1700	0.0000	0.9852	0.0030	0.0148
1750	0.0000	0.9873	0.0030	0.0127
1800	0.0000	0.9891	0.0030	0.0109
1850	0.0000	0.9906	0.0031	0.0094
1900	0.0000	0.9920	0.0031	0.0080
1950	0.0000	0.9931	0.0031	0.0069
2000	0.0000	0.9941	0.0031	0.0059

RECORDS	723
BETA	1.212102
THETA	518.7886
MTBF	487.5005
VARIANCE	162071.9
STD DEV	402.5815

	VALUE	GAMMA
1 + 1/BETA	1.825	0.93969
1 + 2/BETA	2.650	1.48520

Table 6. Weibull Distribution Statistical Functions Data (All failure times)

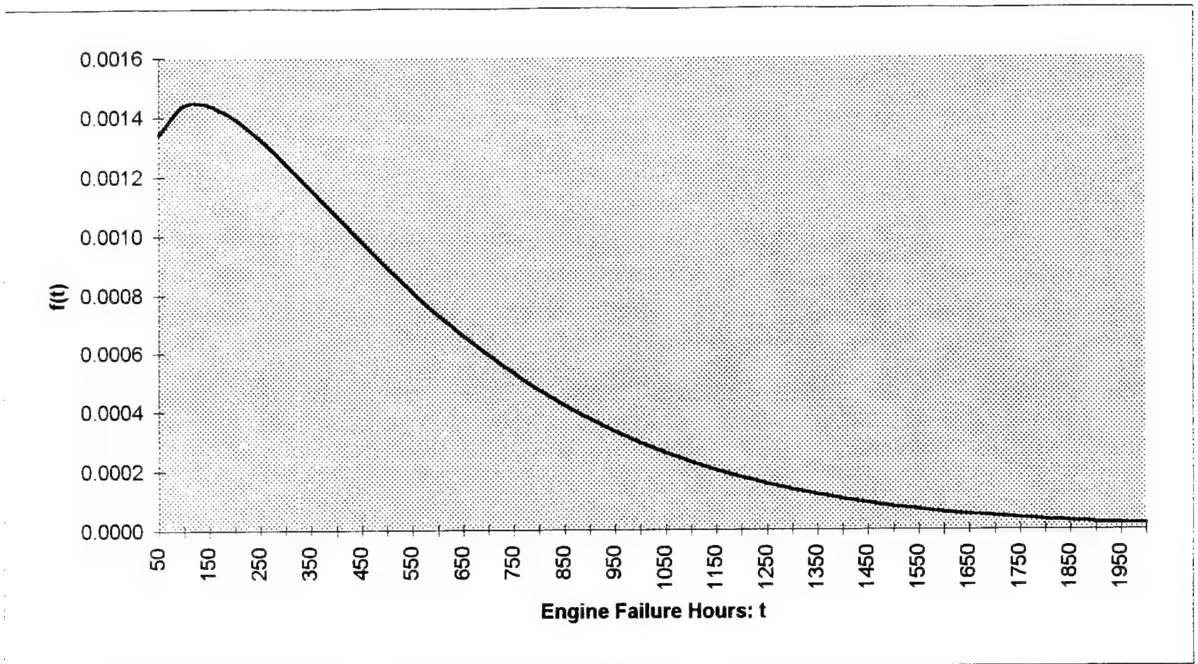


Figure 5. Weibull Distribution PDF (All failure times)

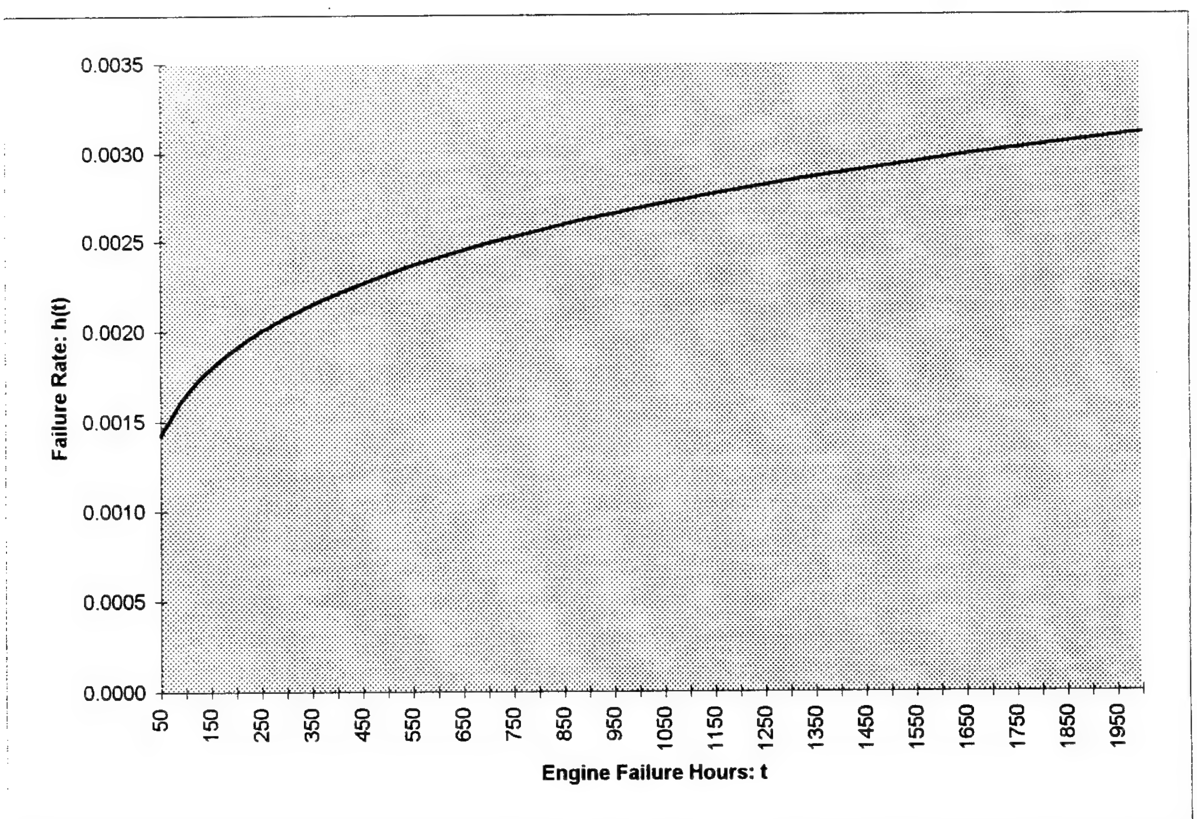


Figure 6. Weibull Distribution Failure Rate (All failure times)

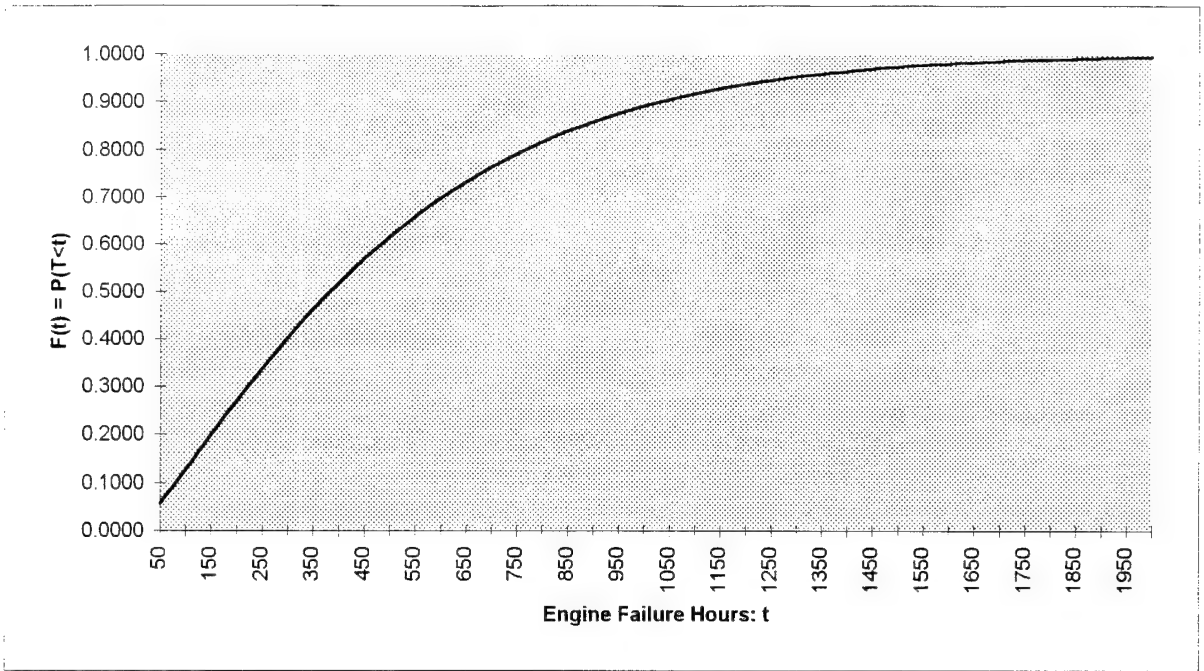


Figure 7. Weibull Distribution CDF (All failure times)

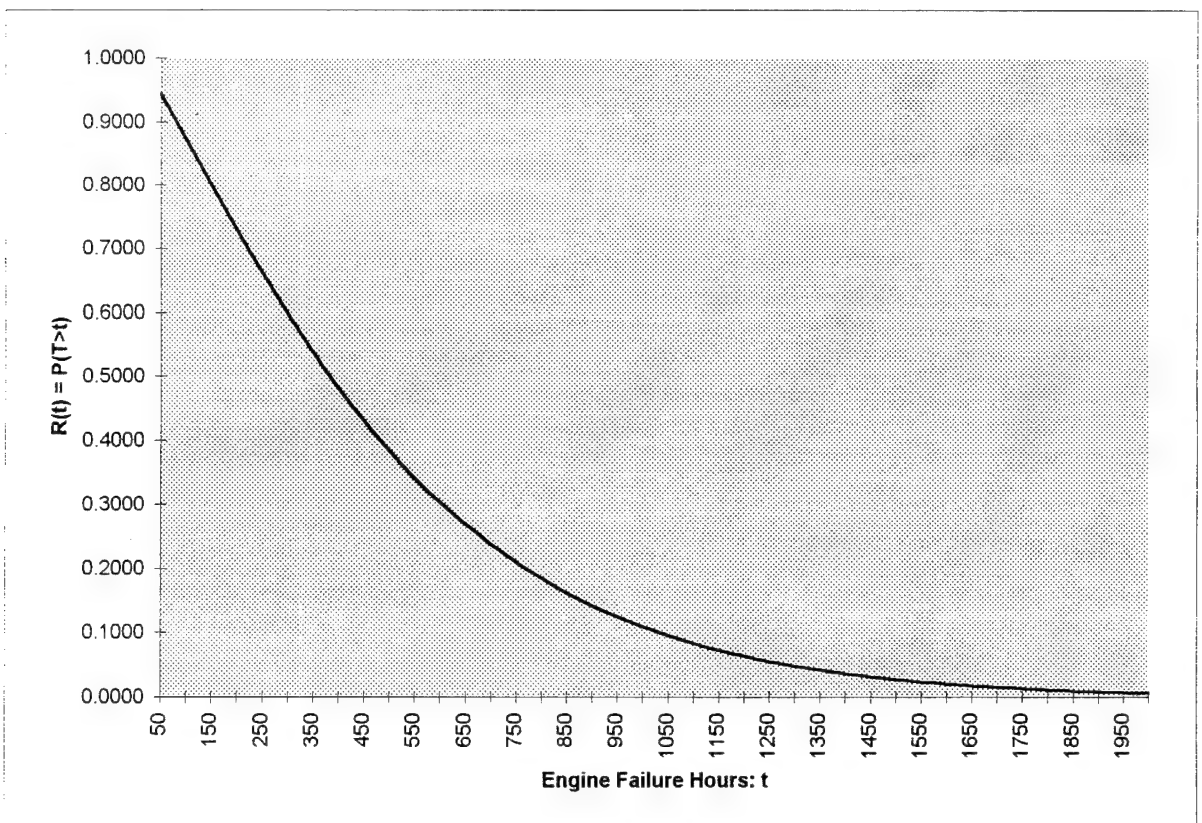
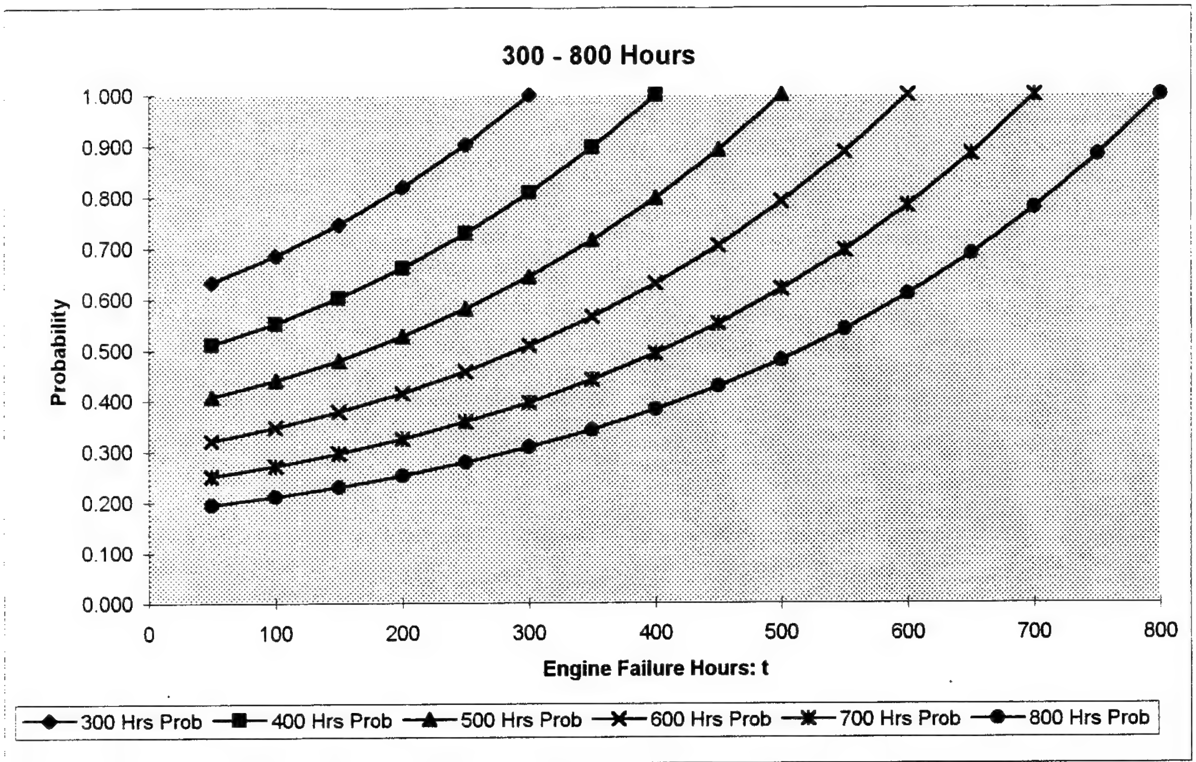


Figure 8. Weibull Distribution Reliabilitiy (All failure times)

Some of these conditional probabilities for selected values of T_0 and t_0 are presented in Table 7 and graphically represented in Figure 9. As in the non-parametric analysis of Chapter II Section B, the number of failure records can be modified and all the calculations can be redone with a new set of data. This will indicate how the parameters can be affected if various data points are removed. Table 8 shows the statistical functional data with zero failure times removed and Table 9 shows the statistical functional data after removing the first 10% of the failure times.

FHRPRP	300 Hrs Prob	400 Hrs Prob	500 Hrs Prob	600 Hrs Prob	700 Hrs Prob	800 Hrs Prob	900 Hrs Prob	1000 Hrs Prob	1100 Hrs Prob	1200 Hrs Prob	1300 Hrs Prob	1400 Hrs Prob	1500 Hrs Prob
50	0.634	0.511	0.408	0.322	0.252	0.196	0.151	0.116	0.088	0.067	0.050	0.038	0.028
100	0.685	0.552	0.440	0.348	0.272	0.211	0.163	0.125	0.095	0.072	0.055	0.041	0.031
150	0.746	0.602	0.480	0.379	0.297	0.230	0.178	0.136	0.104	0.079	0.059	0.045	0.033
200	0.819	0.661	0.527	0.416	0.325	0.253	0.195	0.149	0.114	0.086	0.065	0.049	0.037
250	0.903	0.728	0.581	0.458	0.359	0.279	0.215	0.165	0.126	0.095	0.072	0.054	0.040
300	1.000	0.807	0.643	0.508	0.397	0.309	0.238	0.183	0.139	0.106	0.080	0.060	0.045
350		0.897	0.715	0.564	0.442	0.343	0.265	0.203	0.155	0.117	0.089	0.067	0.050
400		1.000	0.797	0.629	0.493	0.383	0.295	0.226	0.173	0.131	0.099	0.074	0.055
450			0.892	0.704	0.551	0.428	0.330	0.253	0.193	0.146	0.110	0.083	0.062
500			1.000	0.789	0.618	0.480	0.370	0.284	0.216	0.164	0.124	0.093	0.070
550				0.887	0.695	0.540	0.416	0.319	0.243	0.185	0.139	0.105	0.078
600				1.000	0.783	0.608	0.469	0.360	0.274	0.208	0.157	0.118	0.088
650					0.884	0.687	0.530	0.406	0.310	0.235	0.177	0.133	0.100
700					1.000	0.777	0.599	0.459	0.350	0.266	0.200	0.151	0.113
750						0.881	0.679	0.521	0.397	0.301	0.227	0.171	0.128
800						1.000	0.772	0.592	0.451	0.342	0.258	0.194	0.145
850							0.878	0.673	0.513	0.389	0.294	0.221	0.165
900							1.000	0.767	0.585	0.443	0.335	0.251	0.188
950								0.875	0.667	0.506	0.382	0.287	0.214
1000								1.000	0.762	0.578	0.436	0.328	0.245
1050									0.873	0.662	0.499	0.375	0.280
1100									1.000	0.758	0.572	0.430	0.321
1150										0.870	0.657	0.493	0.369
1200										1.000	0.755	0.567	0.424
1250											0.868	0.652	0.488
1300											1.000	0.751	0.562
1350												0.866	0.648
1400												1.000	0.748
1450													0.864
1500													1.000

Table 7. Weibull Distribution Conditional Probability (All failure times)



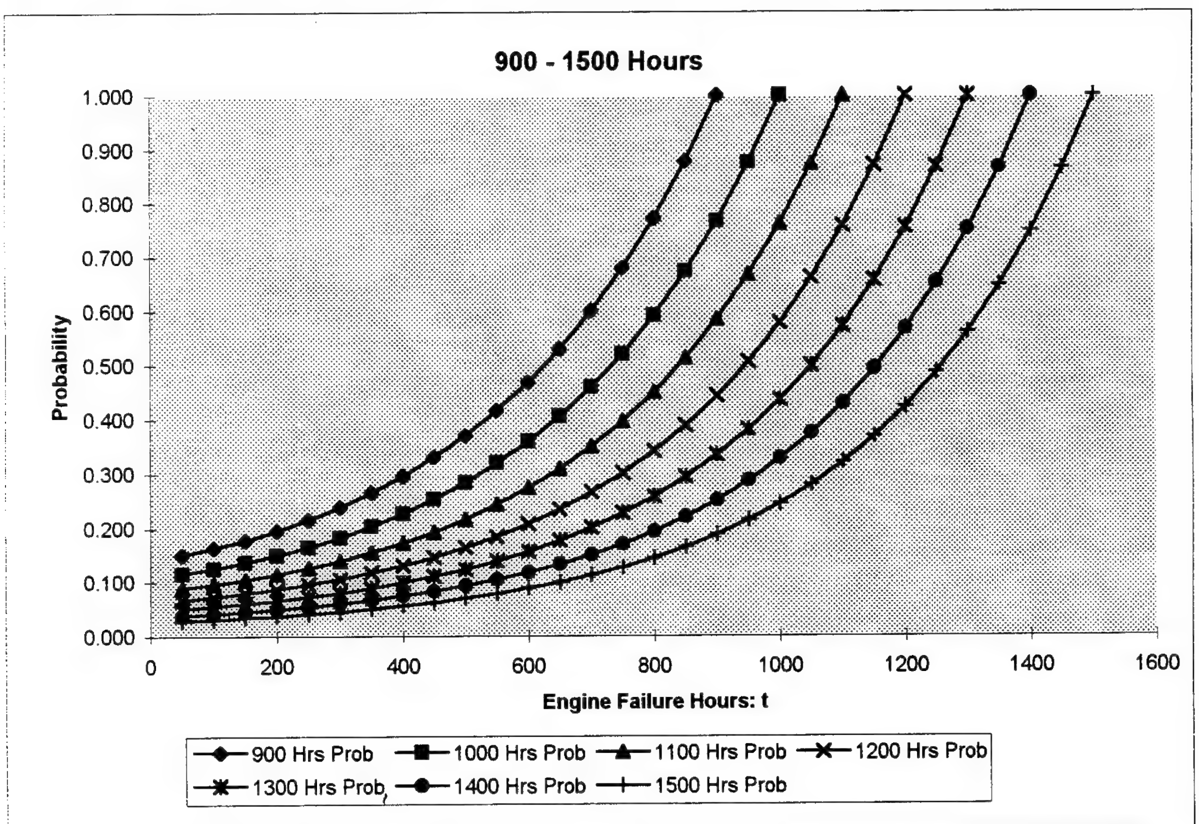


Figure 9. Weibull Distribution Conditional Probability (All failure times)

Failure Times t	Weibull PDF f(t)	Weibull CDF F(t)	Failure Rate h(t)	Reliability R(t)
50	0.0011	0.0416	0.0011	0.9584
100	0.0012	0.0998	0.0014	0.9002
150	0.0013	0.1637	0.0016	0.8363
200	0.0013	0.2294	0.0017	0.7706
250	0.0013	0.2946	0.0018	0.7054
300	0.0012	0.3580	0.0019	0.6420
350	0.0012	0.4185	0.0020	0.5815
400	0.0011	0.4758	0.0021	0.5242
450	0.0010	0.5293	0.0022	0.4707
500	0.0010	0.5789	0.0023	0.4211
550	0.0009	0.6246	0.0023	0.3754
600	0.0008	0.6665	0.0024	0.3335
650	0.0007	0.7046	0.0025	0.2954
700	0.0007	0.7391	0.0025	0.2609
750	0.0006	0.7702	0.0026	0.2298
800	0.0005	0.7982	0.0026	0.2018
850	0.0005	0.8232	0.0027	0.1768
900	0.0004	0.8454	0.0027	0.1546
950	0.0004	0.8652	0.0028	0.1348
1000	0.0003	0.8827	0.0028	0.1173
1050	0.0003	0.8982	0.0028	0.1018
1100	0.0003	0.9118	0.0029	0.0882
1150	0.0002	0.9237	0.0029	0.0763
1200	0.0002	0.9342	0.0030	0.0658
1250	0.0002	0.9433	0.0030	0.0567
1300	0.0001	0.9513	0.0030	0.0487
1350	0.0001	0.9582	0.0031	0.0418
1400	0.0001	0.9642	0.0031	0.0358
1450	0.0001	0.9694	0.0031	0.0306
1500	0.0001	0.9739	0.0032	0.0261
1550	0.0001	0.9777	0.0032	0.0223
1600	0.0001	0.9810	0.0032	0.0190
1650	0.0001	0.9839	0.0033	0.0161
1700	0.0000	0.9863	0.0033	0.0137
1750	0.0000	0.9884	0.0033	0.0116
1800	0.0000	0.9902	0.0034	0.0098
1850	0.0000	0.9917	0.0034	0.0083
1900	0.0000	0.9930	0.0034	0.0070
1950	0.0000	0.9941	0.0034	0.0059
2000	0.0000	0.9951	0.0035	0.0049

RECORDS	684
BETA	1.3092
THETA	558.609
MTBF	514.686
VARIANCE	158295
STD DEV	397.863

	VALUE	GAMMA
1 + 1/BETA	1.764	0.92137
1 + 2/BETA	2.528	1.35621

Table 8. Weibull Distribution Statistical Functions Data (Less zero failure times)

Failure Times t	Weibull PDF f(t)	Weibull CDF F(t)	Failure Rate h(t)	Reliability R(t)
50	0.0009	0.0312	0.0009	0.9688
100	0.0011	0.0799	0.0012	0.9201
150	0.0012	0.1365	0.0014	0.8635
200	0.0012	0.1969	0.0015	0.8031
250	0.0012	0.2588	0.0017	0.7412
300	0.0012	0.3205	0.0018	0.6795
350	0.0012	0.3807	0.0019	0.6193
400	0.0011	0.4387	0.0020	0.5613
450	0.0011	0.4937	0.0021	0.5063
500	0.0010	0.5455	0.0022	0.4545
550	0.0009	0.5938	0.0023	0.4062
600	0.0009	0.6384	0.0024	0.3616
650	0.0008	0.6794	0.0024	0.3206
700	0.0007	0.7168	0.0025	0.2832
750	0.0006	0.7507	0.0026	0.2493
800	0.0006	0.7813	0.0027	0.2187
850	0.0005	0.8088	0.0027	0.1912
900	0.0005	0.8334	0.0028	0.1666
950	0.0004	0.8552	0.0028	0.1448
1000	0.0004	0.8746	0.0029	0.1254
1050	0.0003	0.8916	0.0030	0.1084
1100	0.0003	0.9067	0.0030	0.0933
1150	0.0002	0.9198	0.0031	0.0802
1200	0.0002	0.9313	0.0031	0.0687
1250	0.0002	0.9413	0.0032	0.0587
1300	0.0002	0.9499	0.0032	0.0501
1350	0.0001	0.9574	0.0033	0.0426
1400	0.0001	0.9639	0.0033	0.0361
1450	0.0001	0.9694	0.0034	0.0306
1500	0.0001	0.9742	0.0034	0.0258
1550	0.0001	0.9783	0.0034	0.0217
1600	0.0001	0.9817	0.0035	0.0183
1650	0.0001	0.9847	0.0035	0.0153
1700	0.0000	0.9872	0.0036	0.0128
1750	0.0000	0.9893	0.0036	0.0107
1800	0.0000	0.9911	0.0037	0.0089
1850	0.0000	0.9926	0.0037	0.0074
1900	0.0000	0.9938	0.0037	0.0062
1950	0.0000	0.9949	0.0038	0.0051
2000	0.0000	0.9958	0.0038	0.0042

RECORDS	651
BETA	1.396514
THETA	592.7169
MTBF	540.9016
VARIANCE	153218
STD DEV	391.4306

	VALUE	GAMMA
1 + 1/BETA	1.716	0.91258
1 + 2/BETA	2.432	1.26893

Table 9. Weibull Distribution Statistical Functional Data (Less 10% of failure times)

The Weibull Distribution analysis indicated that as the low data points were deleted the β factor continued to increase. This shows that there may be conditions of wearin immediately after repair that should not be apparent if the distribution truly follows the Weibull Distribution. The data base included numerous values that were very low, so taking the first 10% out only took failure hours up to 10 hours. A different approach was taken to see if filtering the failure hours less than 100 had any appreciable affect on MTBF. The failure hours less than 100 were divided into blocks of ten, and then 50% of each block was deleted selecting random numbers from each block. An additional filtering was performed to remove 80% of each block. The results are listed in Table 10 and indicates that the β has a significant increase and the distribution more closely resembles a Weibull Distriution. Figure 10 illustrates the comparison of the PDF's for all failure times, less zero failure times, less 50% of failure times < 100 hours, and less 80% of failure times < 100 hours. The comparison indicates that as the low value failure times are removed, the distribution more closely resembles a Weibull.

	Less 50% of hours <100	Less 80% of hours <100
Records	636	585
Beta	1.4295	1.7893
Theta	606.19	684.99
MTBF	550.81	609.40
Std Dev	394.07	351.61

Table 10. Weibull Data deleting 50% and 80% of hours <100

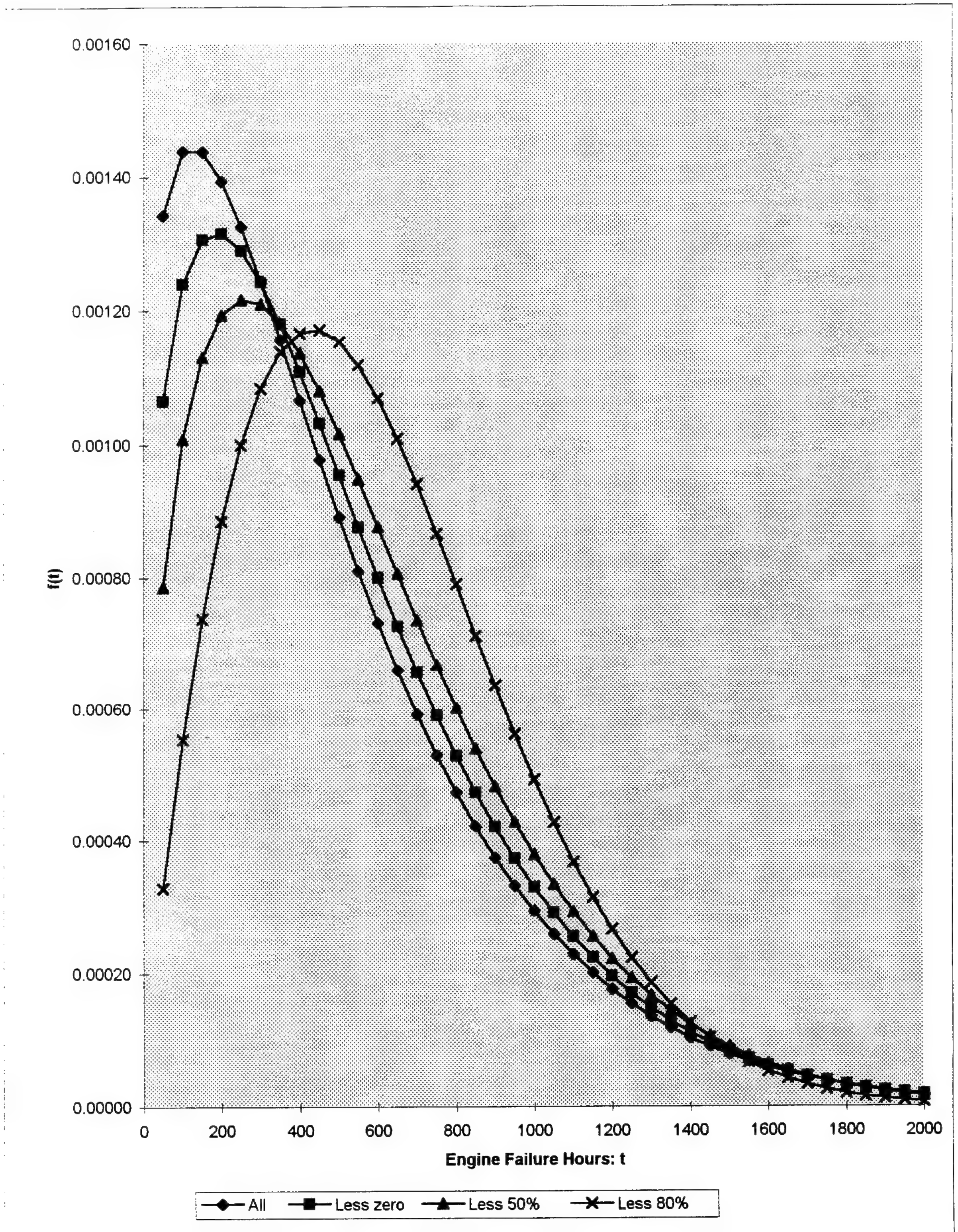


Figure 10. Weibull Distribution PDF Comparison

D. COMPARISON OF ANALYSIS METHODS

Both the non-parametric and parametric methods gave similar results; however, the use of the Weibull Distribution is more useful in advanced analysis and determination of cost-benefit tradeoff analysis. Figure 11 shows the comparison of the CDF's for the modified data base analysis for all failure times, less zero failure times, less 50% of failure times <100, and less 80% of failure times <100.

There is a separation in the curves at the low end generally less than 400 hours, however as the low value failure times are filtered out the curves come closer together and track well together.

A comparison of the Conditional Probability tables using the non-parametric approach and the Weibull fit reveal significant inconsistencies. More analysis needs to be done to determine a more accurate fit of a probability distribution to this population of engines. It may be that the total population of engines can better be divided into two or more subpopulations which could be analyzed separately for more accurate analysis.

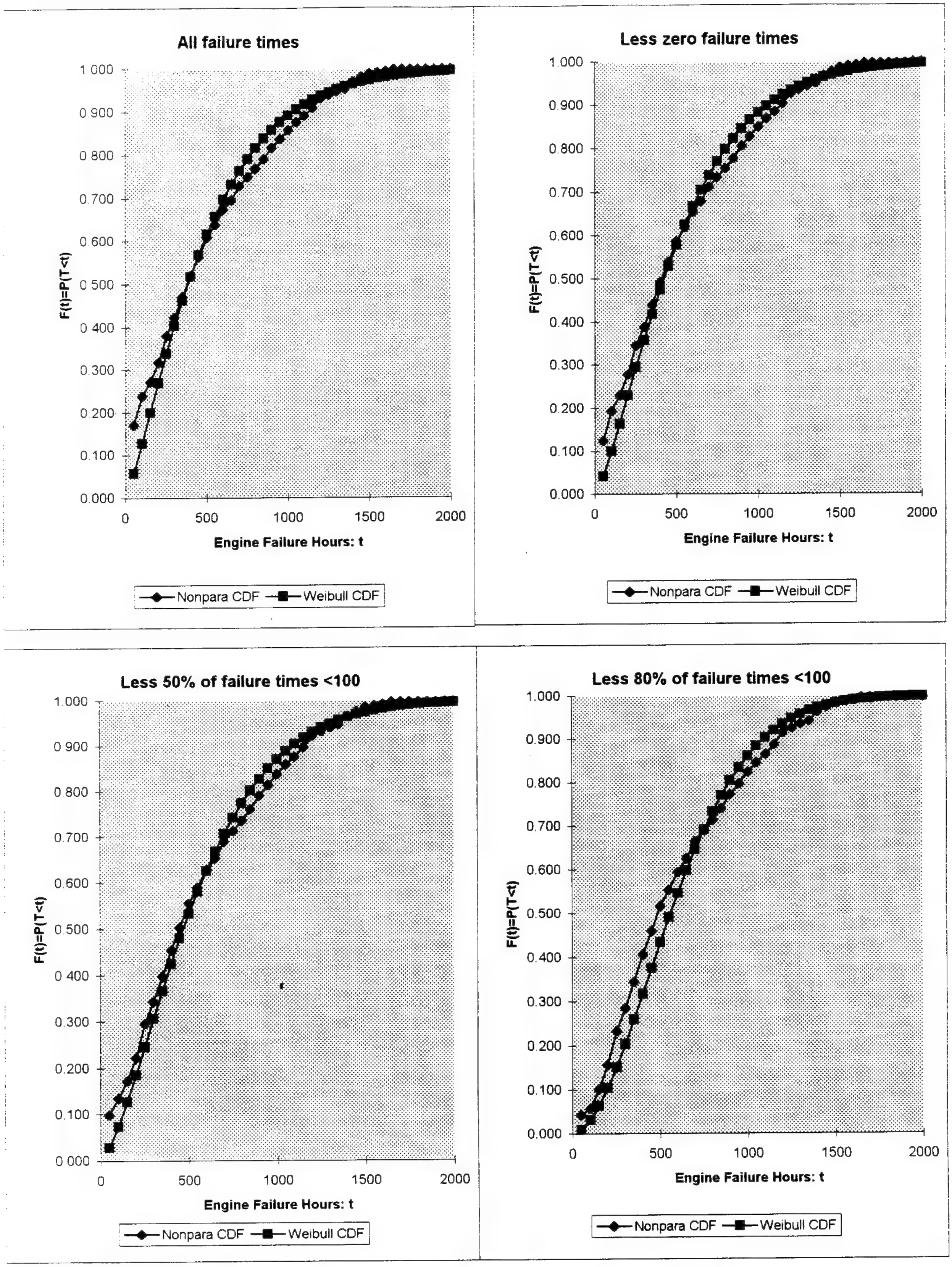


Figure 11. Comparison Nonparametric/Weibull CDF

III. AFFECTS OF CANNIBALIZATION/DIRECTED REMOVALS ON ENGINE MTBF

A. PROCEDURE FOR FILTERING DATA AND CALCULATING STATISTICAL VALUES

While conducting the filtering of the engine removal data for use in the procedures of Chapter II Sections B and C, there seemed to be a correlation between cannibalization's and directed removals with subsequent failures of the engines and the potential impact on engine MTBF. Only failures that potentially could be attributed to a maintenance action were included in this analysis. The full data base was looked at again and the following systematic approach was used to filter the data for further analysis:

Step 1: Using the same query as used in Chapter II Section A, and after decoding, the data was imported into a spreadsheet software program. Each entry was manually reviewed and compared to what occurred in the previous entry. All entries that had either a cannibalization removal code of 3W or directed removal code of 4D and the subsequent entry were kept and all other entries were deleted. If the last entry on an engine was a 3W or 4D it was also deleted if it did not have a previous 3W or 4D. Removal reason codes 3E (faulty handling/dropped), 4B (accident/incident damage), 5A (firefighting chemical ingestion), 5C (FOD compressor), 5D (FOD turbine) were also deleted since these removal codes were not caused by a previous maintenance action. This resulted in a total of 1036 related entries and are listed in Appendix C.

Step 2: Compare the entries and manually calculate the number of hours the engine operated until the next entry. These times are then put into several categories related to the combination of entries. These categories are:

- Cannibalization removal followed by failure removal - An entry here meant that after the cannibalization the next entry was an engine failure removal reason.

- Cannibalization removal followed by scheduled removal - An entry here meant that after the cannibalization the next entry was an engine removal for high time removal reason (Codes 5G, 7C, and 7D).

- Cannibalization removal followed by cannibalization or directed removal - An entry here meant that after the cannibalization the next entry was an engine removal for either another cannibalization or directed removal.

- Directed removal followed by failure removal - An entry here meant that after the directed removal the next entry was an engine removal failure reason.

- Directed removal followed by scheduled removal - An entry here meant that after the directed removal the next entry was an engine removal for high time removal reason (Codes 5G, 7C, and 7D).

- Directed removal followed by cannibalization or directed removal - An entry here meant that after the directed removal the next entry was an engine removal for either cannibalization or another directed removal.

Step 3: Using the statistical capability of the spreadsheet calculate the mean, standard deviation, median, minimum value, maximum value, and manually add up the total number of entries for each category. The results are listed in Table 11. Table 11 shows the mean time to the next failure after cannibalization is 247 hours.

B. AFFECTS ON ENGINE MTBF

The analysis of Chapter II Sections B and C only took into account engine failures without relating the failure to any previous maintenance action. The ERAP Removal/Downgrade report specifically states that "Cannibalization is not accounted for in this report because it does not require a repair". (ERAP, 1995) The report also does not count directed removals, but is not specifically referenced in the ERAP. The purpose of the Removal/Downgrade report is to display unscheduled vs scheduled removals and engine downgrades. Table 1 shows that of the 1812 engine removals 777 (43%) were for either cannibalization or directed removal.

Category	Mean	Std Dev	Median	Min	Max	# of Records
Cannibalization followed by failure	247	274	159	0	1140	180
Directed Removal followed by failure	74	83	0	0	688	74
Totals	197	258	159	0	1140	254
Cannibalization followed by scheduled removal	368	388	204	0	1473	78
Directed Removal followed by scheduled removal	251	275	171	0	988	42
Totals	327	356	184	0	1473	120
Cannibalization followed by Cannibalization or Directed Removal	213	269	126	0	1305	214
Directed Removal followed by Cannibalization or Directed Removal	166	172	132	0	737	36
Totals	207	258	129	0	1305	250
Cannibalization Totals	283	317	176	0	1473	472
Directed Removal Totals	251	224	10	0	988	152
Cannibalization and Directed Totals	225	283	124	0	1473	624

Table 11. Cannibalization and Directed Removal Statistics

The information in Table 11 clearly indicates that MTBF is affected by the actions that occur at the maintenance activities when an engine is pulled for either a cannibalization or directed removal. It is significant to note that the median hours for a failure removal after a directed removal is zero hours with a mean of 74 hours. Fourty percent of the removals for cannibalization or directed removal are followed by a removal for a failure reason. A review of the data in Appendix C shows that the engines have a mean operating time of 469 hours at the time the engine is removed for cannibalization reasons.

IV. PERFORMANCE GOAL SETTING

A. INFANT MORTALITY GOALS

In Chapter II Section B, the relationships between wear-in/wear-out and the conditional probability function $R(t + h|t)$ was analyzed. The computation in that section revealed that wear-in tends to approach zero for engines with failure times of about 400 hours. The failure rate function for this set of data has a shape similar to the famous "bathtub curve" associated with the lifecycle of equipment as illustrated in Figure 12.

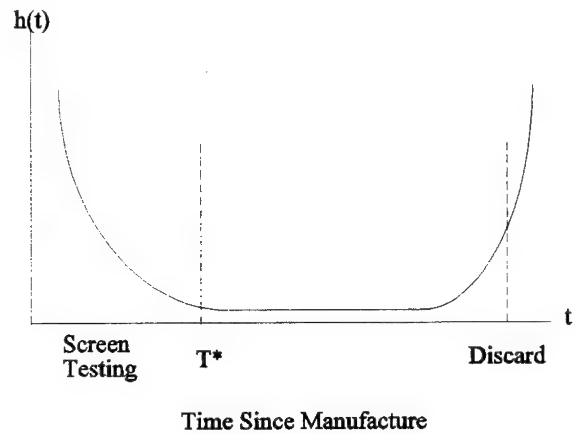


Figure 12. Bathtub Curve

The failure rate curve is decreasing (wear-in) during screen testing because early failures are being removed from the population of items as time since manufacture (test time) increases.

The population of TF-34 engines is far more complex than new engines coming off a production line, because the state of repair of the engines being reintroduced into the population of operating engines has much larger variation than a population of new engines. Whatever these factors are that influence variation in operating condition of repaired engines, the net effect of the maintenance program, the cannibalization program

and related programs yield a population of operating engines with a failure rate function similar to the bathtub curve in Figure 12. The time T* is the failure time that defines infant mortality time.

In acquisition programs, it is commom practice to label items with failure times less than T* as infant mortality items. It is suggested that this same concept be used to define infant mortality in the TF-34 Engine Improvement Program. That is, *Infant Mortality times are those failure times less than time t, where t is determined from the equation* $R(2t|t) \cong R(t)$ *using Table 2 and Table 3 Non-parametric Conditional Probabilities.* Using this definition, infant mortality times are all times less than 400 hours since $R(800|400) = R(400) = 0.48$, and for nearly all failure times $t < 400$, $R(2t|t) > R(t)$.

It is desirable to have zero Infant Mortality times in a data base. If all failure times less than 400 hours in the data base were deleted, the relation $R(800|400) = R(400)$ would still hold. But if no engines failed before time 400, many more failure times larger than 400 hours would appear in the consequent data base. This would create a higher MTBF.

Clearly, the best way to improve infant mortality is to improve the maintenance capability of the engines in a manner that reduces the number of small failure times.

B. MTBF GOALS

Engine failures result in unscheduled maintenance actions and unscheduled engine removals regardless of the length of operating times on the engine when it fails. A review of the data base in Appendix A reveals that 172 of the total 723 engine failure times were less than 100 hours. This is nearly 24% of all engine failure times. If maintenance capability (training, staffing, parts availability, etc.) improved so that 80% of these failure times were no longer in the data base, the MTBF would increase and the number of unscheduled maintenance actions would decrease. Table 14 shows that the MTBF would increase from approximately 480 hours for the existing data base to about 600 hours were these "80% group" of failures removed. Actually the resultant MTBF would be larger because larger operating times would appear in the data base.

Table 12 also displays the resulting MTBF if only 50% of these "less-than-100 hour" failure times are removed; namely 545 hours versus the 480 hours for the entire data base.

	# of failures	Beta	Theta	MTBF	Std Dev
Weibull (All)	723	1.2121	518.787	488	403
Weibull (Less zero)	684	1.3092	558.609	515	398
Weibull (less 10%)	651	1.3965	592.717	541	391
Weibull (Less 50% <100 hrs)	636	1.4295	606.195	551	394
Weibull (Less 80% <100 hrs)	585	1.7893	684.995	609	352
Nonpara (All)	723	N/A	N/A	480	421
Nonpara (Less zero)	684	N/A	N/A	507	416
Nonpara (Less 10%)	651	N/A	N/A	533	410
Nonpara (Less 50% <100 hrs)	636	N/A	N/A	541	412
Nonpara (Less 80% <100 hrs)	585	N/A	N/A	586	399

Table 12. Non-parametric/Weibull Statistical Data Comparison

Selecting the goal for MTBF using this criteria of eliminating a given percentage of the less-than-100 hour failures describes the method for achieving the goal which in turn provides a goal for quality improvement in maintenance capability.

An alternative method for setting an MTBF goal is to establish new policy regarding maintenance after removal for cannibalization and directed removal. Table 12 strongly indicates that an increase in MTBF could be obtained if maintenance policy was implemented that brought MTBF for the failure times subsequent to cannibalization or directed removals up to the level of the overall population of engines.

C. UNSCHEDULED MAINTENANCE ACTIONS (UMA)

Since each engine failure produces an UMA, a reduction in the number of small failure times will reduce the number of UMA's. But UMA's will also be reduced by extending the lifetime of any engine. The average number of UMA's, ANUMA, for the entire fleet of engines for any reporting period depends on the set of current accumulated operating times, t_i, for each engine in the population; the length of the reporting period, T_R; and the total operating hours till the next scheduled removal, T_0. Specifically, for the i^{th} operating engine in a population of N engines

t_i = current accumulated operating time at beginning of the reporting period

t_r = hours of the reporting period length, T_R, that the engine operates

t_{oi} = total operating time till the next scheduled removal

then,

$$ANUMA\ (T_R) = N - \Sigma\ R(\ t_{0i}^{*}\ |\ t_i\ ) \tag{27}$$

where,

$$t_{0i}^{*} = Min\ \ (t_r + t_i\ ,t_{0i}\ ) \tag{28}$$

and R(t*|t) is computed from Table 3.

As an example of how to apply Equations 27 and 28, assume N = 10 engines; each engine has a t_i of 200 hours; eight of the engines have a t_{0i} of 800 hours; one engine has a t_{0i} of 500 hours; one engine has a t_{0i} of 400 hours; each engine operates 33 hours per month, the reporting period is one year, which gives a t_r of approximately 400 hours. The minimum of $(t_r + t_i)$ and t_{0i} is used to determine t_{0i}^*, therefore t_{oi}^* for eight of the engines is 600; for the engine with a t_{0i} of 500, t_{0i}^* is 500; and the engine with a t_{0i} of 400, t_{0i}^* is 400. Using Table 3, $R(t_{0i}^*|ti)$ for eight of the engines is 0.478; the engine with a t_{0i}^* of 500, $R(t_{0i}^*|ti)$ is 0.573; and the engine with a t_{0i}^* of 400, $R(t_{0i}^*|ti)$ is 0.702. Summing these

probabilities gives a total of 5.099 and subtracting this from 10 engines gives an ANUMA of 4.901 or approximately 5 unscheduled maintenance actions will occur during the next year for this population of 10 engines.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The following topics are covered in this thesis:

- Discussion of ERAP and related reports
- Demonstration of non-parametric and parametric methods for calculating MTBF and related statistical distribution functions for the a fielded jet engine
- Demonstration of non-parametric and parametric procedures for calculating the conditional probability that a fielded jet engine will last to the next scheduled maintenance interval given the number of hours since last repair
- Demonstration of filtering out different sets of data and its impact on the MTBF and related statistical distribution functions for a fielded jet engine
- Demonstration of commercially available spreadsheet software (EXCEL 5.0) to develop statistical distributions using the NALDA data base
- Discussion of the impact of cannibalization and directed removals on the MTBF of a fielded jet engine
- Demonstration of a procedure for determining the infant mortality point for a fielded jet engine
- Discussion of the impact low failure times have on MTBF of a fielded jet engine
- Demonstration of a procedure for determining the ANUMA for a given reporting period for a fielded jet engine.

B. CONCLUSIONS

The NALDA data base is ponderous, not user friendly and needs to have improvements incorporated in order to keep pace with requirements for lower cost logistic support and the associated need for powerful real time feedback for decision support. The

lack of student's and staff access to or familiarity with NALDA impairs the ability of the resources available at the Naval Postgraduate School (NPS) to be utilized to their fullest capability. The fact that the NALDA data base access is not user friendly also increases funding requirements for thesis travel, impacts students class schedule, and impacts the work schedules of those technicians who currently use NALDA and provide assistance to thesis students. LMDSS holds the solution to many of the problems mentioned and would significantly increase the resource utilization at NPS when the system eventually goes on line.

The standard queries and subsequent automatic filtering of the NALDA data base used in the generation of the ERAP reports is a good tool for a snapshot picture of the day to day operations and analysis. However a more indepth analysis of how maintenance actions are related (i.e., subsequent failures after cannibalization or directed removal) should be undertaken to provide the proper analysis for making logistic decisions on fielded jet engines.

Both the Non-parametric and Weibull Distribution Analysis give comparable results for MTBF, indicating that either analysis could be used for determining performance goals. However, the Weibull Distribution does not have a sufficiently good fit due to the high number of failure hours less than 100 hours. Until this large number of low failure hours can be reduced, the Non-parametric analysis should be used for any statistical analysis. The Weibull Distribution does provide the logistic manager a tool to make cost benefit tradeoffs by applying a known distribution to the cost formulas and would be benefical to future logistics planning.

The large number of failure times less than 100 hours (24% of the total failure times) has a significant impact on the engine MTBF and indicates that the engines are experiencing a wear-in period (infant mortality) up to approximately 400 hours. Current maintenance practices require that an engine in for repair will also have any component replaced that will reach a scheduled high time removal within 500 hours after repair. Therefore engines are not being repaired to an "as new condition". Engines are returned to the fleet with a number of high time limiting components having various life

expectancies. With the current policy of replacing components within 500 hours, the data in Table 3 shows that the current population of engines have no more than a 50% chance of making the next scheduled removal as soon as the engine repair is complete. Reducing the value of when high time components are replaced to 300 hours would increase the probability of reaching the next scheduled removal, but this increase reliability must be traded off with the increase in frequency of scheduled maintenance.

The high number of low failure values is indicative of a quality problem in the repair process and could be contributed to the following areas;

- Maintenance Technician Training - inadequate training on proper procedures for work area cleanliness, following maintenance procedures, proper fault diagnosis, and proper reporting of actions taken.
- Repair Parts - the supply system could be providing substandard repair parts, either from procurement of new items or reuse of aviation repairables that have been repaired at the maintenance depot.
- Maintenance Procedures - inadequately written procedures that do not provide proper guidance on disassembly or reassembly, work area cleanliness, and fault diagnosis.
- Tools - the proper tools are not available to perform the maintenance action.

If 80% of the failure hours less than 100 hours can be resolved, then there is a potential to increase MTBF by 20%, with a subsequent savings in maintenance dollars in both parts and labor, less plane downtime and better maintenance scheduling.

The maintenance actions that are performed on engines removed for cannibalization or by direction significantly impacts the engine's ability to reach its next scheduled removal interval. These maintenance actions are causing failures that may not have occurred if the engine was allowed to operate until its next scheduled removal without interference. Cannibalizations have a devastating impact on engine reliability and future logistics support planning. If cannibalizations are considered standard practice then it is impossible to set performance goals and achieve them. Cannibalizations are a short-

sighted strategy with significant long-term implications and are indicative of problems in the logistic support system. These problems could be related to an insufficient number of spare engines, long turn-around-time in the logistic pipeline (i.e., supply distribution system, maintenance time at the depots), insufficient range or depth of repair parts on the ship or at the squadron, improper maintenance technician training, or lack of funding.

Directed Removals are another area of concern that is also a short-sighted strategy and indicative of problems in the logistic support system. These engines are being directed to be transferred to another unit by higher authority to meet an urgent operational need. It is especially disturbing to note that the median failure time after a directed removal is zero hours and the mean is only 74 hours. This not only impacts the readiness of the unit that gave up the engine, but their is a high potential that the urgent operational need is now not going to be met. This also adds additional costs to the logistic support system in both transportation and labor costs.

C. RECOMMENDATIONS

The following recommendations are provided as a result of the research performed in this thesis:

1. Reformat the Removal/Downgrade report to capture failures after cannibalization or directed removals to track the potential that these maintenance actions have on engine failures.

2. Engine Logisticians should conduct manual analysis of the NALDA database and not just rely on the standard ERAP reports for making logistic decisions. The manual filtering of the data can be accomplished in a matter of a few hours, and with the use of spreadsheet software programs, the manipulation of the data and subsequent calculations of descriptive statistics is readily accomplished. Once the initial data is filtered, additional entries should only take a minimal amount of time.

3. Due to the impact cannibalizations have on future engine failures, this type of removal should be analyzed from a cause and effect viewpoint. This analysis should take into account why cannibalizations are being performed and who is performing the cannibalizations. The analysis should also review the quality control

procedures that are in place to ensure other damage is not being done to the engine, if a cannibalization must be performed.

4. Due to the impact directed removals have on future engine failures, this type of removal should be analyzed from a cause and effect viewpoint. This analysis should take into account why directed removals are being performed and who is performing the removal and subsequent installation. The analysis should also review the quality control procedures that are in place to ensure other damage is not being done to the engine, if a directed removal must be performed.

5. Continue to analyze the population of engines and their failure times to establish a better parametric probability distribution fit to the data than the Weibull fits developed in this thesis. A good parametric fit for the entire population of engines or to a subpopulation of engines will support cost-effective trade-off studies and engine allocation studies.

6. NALDA access via LMDSS should implemented at NPS as soon as possible. This will show significant cost savings in thesis travel and more fully utilize the resources available. This installation should also include training for the computer center personnel as a foundation for further training of students working on thesis in aviation related areas.

7. An analysis of the large number of failure times less than 100 hours should be analyzed from a cause and effect viewpoint. This analysis should review the maintenance procedures, quality control procedures and training of the maintenance personnel at the maintenance activity.

LIST OF REFERENCES

Engine Reliability Analysis Program (ERAP) Reports Users Manual, Naval Air Warfare Center Aircraft Division Propulsion and Power Engineering, February, 1995.

Engine Reliability Analysis Program (RAP) Software Users Manual, Naval Air Warfare Center Aircraft Division Propulsion and Power Engineering, February, 1995.

Lucas, Steve A. and T.E. Hammond, *Methods for Continuous Improvement of Fielded Jet Engine Reliability and Maintainability,* Master's Thesis, Naval Postgraduate School, Monterey, California, December, 1994.

BIBLIOGRAPHY

Bain, L.J. and M. Engelhardt, *Statistical Analysis of Reliability and Life-Testing Models*, Marcel Dekker, Inc., 1991.

Bain, L.J. and M. Engelhardt, *Introduction to Probability and Mathematical Statistics*, PWS-Kent Publishing Company, 1992.

Weast, R.C., *Standard Mathematical Tables 13th Edition*, The Chemical Rubber Co, 1953.

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0201021	3359	33	2474	7K	1	3Q
* 0201022	3076	301	2474	3Q	1	2N
* 0201022	3115	39	2474	8P	1	3Q
* 0201101	4805	685	2474	4P	1	5G
* 0201101	5295	490	2474	1Z	3	6F
* 0201102	5148	310	2474	4M	3	5G
* 0201102	5236	88	2474	1Z	1	4M
* 0201102	6068	20	2474	3T	2	7C
* 0201103	5428	1018	2474	3D	3	1Z
* 0201103	5431	3	2474	5Q	2	3D
* 0201104	5166	293	3372	3A	2	1Z
* 0201104	5327	161	2474	6N	3	3W
* 0201104	6416	1089	2374	3R	1	6J
* 0201106	5833	994	2474	2N	1	5Q
* 0201108	5485	465	2474	5Q	1	7C
* 0201109	3606	211	2474	5C	2	5G
* 0201110	5431	1030	2474	8B	2	7C
* 0201110	5652	221	2474	3T	1	6Q
* 0201110	5670	18	2474	3T	1	5Q
* 0201111	5539	271	2474	7A	2	7C
* 0201111	5895	356	2474	1B	1	7A
* 0201111	6136	241	3372	3R	2	1B
* 0201112	5189	927	2474	3P	3	5G
* 0201112	5804	615	2474	3Q	1	3M
* 0201113	5313	262	2474	1Z	1	3Q
* 0201113	5335	22	2474	2N	1	1Z
* 0201113	5914	579	2474	6F	2	3B
* 0201113	6057	143	2474	1Z	1	6F
* 0201114	4807	1100	2474	3M	1	5C
* 0201117	6415	15	2474	3T	1	7C
* 0201118	5056	67	2474	6F	1	7D
* 0201118	5094	0	2475	4A	2	6F
* 0201119	5247	0	2474	1G	2	7C
* 0201119	5569	322	2474	6Q	2	7C
* 0201119	5600	31	2474	6F	1	4P
* 0201120	5041	15	2474	6N	2	7D
* 0201120	5041	0	3372	6Q	3	4A
* 0201120	5464	423	2474	3R	1	6Q
* 0201121	2913	1423	2474	5Q	1	4M
* 0201124	2360	959	2474	1G	1	3Q
* 0201124	2530	170	2474	1Z	1	1R
* 0201124	2920	163	3372	3R	1	5G
* 0201127	4525	294	2474	4M	2	7C
* 0201127	4600	75	2474	6F	1	4M
* 0201127	4825	225	2474	4R	3	6F
* 0201127	4828	3	2474	3D	3	4R
* 0202001	5199	1470	2474	3T	2	6F

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202003	4538	822	2474	1G	1	5C
* 0202003	5276	738	2474	3R	2	1G
* 0202003	6265	989	2474	5Q	1	3R
* 0202004	5774	692	2474	3R	1	7C
* 0202005	4762	615	2474	1Z	1	3Q
* 0202005	5212	450	2474	3Q	1	1Z
* 0202005	5317	105	2474	1W	1	3Q
* 0202006	6106	668	2474	6P	2	7D
* 0202007	2311	533	2474	3T	2	7C
* 0202007	2562	251	2474	1Z	3	3W
* 0202007	3053	491	2474	6J	2	1Z
* 0202008	3505	51	2474	3Q	1	1Z
* 0202009	5251	406	2474	1G	2	7C
* 0202009	5251	0	2474	2N	2	1G
* 0202009	5908	0	2475	3B	3	7C
* 0202009	5997	89	2474	5Q	2	3B
* 0202009	6390	482	2472	6N	2	3B
* 0202010	4107	415	2474	1G	1	5C
* 0202010	4406	299	2474	3Q	1	3Q
* 0202011	4048	358	2474	3Q	2	7C
* 0202011	4051	3	3372	3R	1	3T
* 0202012	4532	385	2474	6E	2	1Z
* 0202012	5812	427	2474	6F	2	7D
* 0202012	6559	747	2474	6J	2	6F
* 0202014	3663	1353	2474	6N	1	7E
* 0202015	4361	1327	3372	3A	3	5C
* 0202016	5411	504	2474	1Z	3	3R
* 0202018	4135	229	2474	1Z	1	3R
* 0202022	4387	40	2474	3T	1	7D
* 0202022	5880	640	2474	5Q	2	3B
* 0202023	4757	770	2474	3P	1	1Z
* 0202023	5504	747	2474	5Q	2	3P
* 0202024	3979	508	2474	1W	1	7C
* 0202024	4778	67	2474	3D	2	7D
* 0202024	4908	130	2474	3P	1	3D
* 0202025	5229	954	2474	5C	2	1Z
* 0202025	5229	0	2475	3R	2	5D
* 0202025	5380	151	2474	1W	2	3R
* 0202026	5538	516	2474	1Z	3	5C
* 0202027	4412	1441	2474	3T	2	7K
* 0202028	4177	998	2174	5Q	2	3Q
* 0202028	4694	517	2474	6Q	1	3T
* 0202029	5509	975	2474	2S	1	7C
* 0202030	3567	688	2474	1Z	1	2N
* 0202030	3846	279	2474	1Z	2	1Z
* 0202030	4972	1126	2474	5Q	2	1Z
* 0202031	5534	791	2474	6F	1	6Q

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202031	5880	346	2474	5Q	2	6F
* 0202033	4307	1183	2474	3A	2	8F
* 0202033	4600	293	3372	5C	1	3U
* 0202034	2929	155	2474	5W	2	7C
* 0202034	4141	1212	2474	3Q	1	5C
* 0202035	3213	595	2474	3U	2	7C
* 0202035	3215	2	2474	3A	1	3U
* 0202035	3297	82	2474	1W	2	3A
* 0202036	6133	1066	2474	3Q	3	7C
* 0202036	6666	1	2474	5Q	1	7D
* 0202036	6786	120	2474	2S	2	5Q
* 0202036	7037	251	2474	3T	2	2S
* 0202037	4957	2	2474	6F	1	7K
* 0202037	5283	326	2474	5C	3	3W
* 0202038	3566	942	2474	1Z	1	7D
* 0202042	5606	596	2474	3R	1	7C
* 0202042	5606	596	2474	7K	1	7C
* 0202042	5784	178	2474	1T	2	7K
* 0202045	2885	485	2474	6J	2	1Z
* 0202045	2929	44	2474	3R	3	5C
* 0202045	3008	79	2474	5Q	1	3U
* 0202045	3310	302	2474	3R	2	7D
* 0202047	3512	210	2474	1W	2	1A
* 0202047	3652	140	2474	5Q	2	1W
* 0202048	5037	424	3372	1W	1	1Z
* 0202048	5976	939	2474	1Z	1	3T
* 0202049	5186	1320	3372	5Q	2	1Z
* 0202049	5196	10	2474	8P	3	5Q
* 0202049	5468	272	2474	5Q	2	6A
* 0202049	6041	573	3372	3R	2	5Q
* 0202051	3605	480	3372	3A	1	2N
* 0202051	3989	384	2474	6N	1	3R
* 0202051	4118	129	2474	5Q	2	6N
* 0202052	4466	555	3372	3A	2	7C
* 0202053	5762	761	2474	3Q	2	7C
* 0202053	6011	249	2474	3R	2	3Q
* 0202053	6243	232	2474	8F	2	3R
* 0202054	3314	656	2474	5C	1	5B
* 0202054	3349	35	2474	6F	2	5C
* 0202054	3814	465	2474	3M	2	6F
* 0202055	5376	592	2474	7L	1	6F
* 0202055	5387	11	2474	1W	3	7L
* 0202056	3600	1103	2474	3R	2	7C
* 0202058	5065	320	2474	4R	2	7D
* 0202060	4917	460	2474	6N	1	5D
* 0202060	5339	422	2474	3R	2	6A
* 0202062	4464	40	2474	1W	1	7C

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202062	5027	563	3372	3A	1	2N
* 0202063	3016	722	2474	5D	1	8F
* 0202063	3131	115	2474	7K	2	3B
* 0202063	3136	5	2474	8C	2	7K
* 0202063	3716	0	2472	3B	2	7C
* 0202063	3751	35	2474	7K	2	3B
* 0202064	5122	809	2474	7A	1	5C
* 0202064	5122	0	2475	7A	2	7A
* 0202064	5834	5	3372	2S	1	7C
* 0202065	3090	436	2474	8F	2	7C
* 0202065	3212	122	2474	3Q	1	3T
* 0202067	2761	1096	2474	3P	3	5C
* 0202068	4683	236	2474	5Q	1	7C
* 0202068	5022	338	2474	1W	1	5Q
* 0202069	5422	138	2474	7K	2	7D
* 0202069	5422	0	2472	2Q	1	7K
* 0202070	4390	3	2474	5Q	1	7C
* 0202070	5625	1235	2474	7T	2	5Q
* 0202071	3943	178	2474	1W	2	7C
* 0202072	3636	1638	2474	5Q	2	1Z
* 0202074	3558	199	2474	2N	3	3W
* 0202074	4217	659	3372	6Q	2	2N
* 0202075	2865	1006	2474	5C	2	3T
* 0202075	4219	1354	2474	6N	3	5C
* 0202075	4225	6	2474	2N	2	7C
* 0202075	4225	0	2474	3R	2	8F
* 0202075	4239	14	2474	8C	2	3B
* 0202076	3715	83	2474	2N	3	7C
* 0202076	4161	327	2174	5Q	1	7C
* 0202078	2976	99	2474	1Z	1	4D
* 0202078	3057	81	3372	3R	2	1Z
* 0202080	5481	3	2474	3P	1	7C
* 0202080	5483	2	2474	3P	3	3M
* 0202081	5641	1283	3372	3R	3	4P
* 0202083	3548	405	2474	2C	3	7J
* 0202083	4683	1135	2474	1G	1	2C
* 0202084	6540	70	2474	1B	2	7D
* 0202085	4858	82	2474	1W	2	7D
* 0202086	2080	116	2474	3Q	3	3R
* 0202086	2147	67	2474	3T	2	2S
* 0202086	2355	11	2474	2S	1	5W
* 0202086	2572	217	3372	6Q	1	2S
* 0202087	4339	1285	2474	5Q	3	7K
* 0202087	4406	67	2474	5Q	1	5Q
* 0202088	4828	912	2474	3R	1	1G
* 0202088	6054	362	2474	6F	2	7C
* 0202089	4435	226	2474	7A	1	5C

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Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202089	4442	7	2474	7J	2	7J
* 0202089	4971	529	2474	3Q	2	7J
* 0202089	4987	16	2474	5D	1	6Q
* 0202090	3437	376	2474	1Z	1	7C
* 0202090	3437	0	2474	2C	1	2A
* 0202091	4062	168	2474	1Z	3	7D
* 0202091	4062	168	2474	5C	3	7D
* 0202091	4676	614	2474	2C	1	6Q
* 0202092	3475	228	2474	1G	1	5C
* 0202093	4613	703	3372	3R	2	7C
* 0202095	5694	89	3372	1Z	2	7C
* 0202096	2036	0	2475	3B	2	7C
* 0202096	3318	1282	2374	6R	2	3B
* 0202097	4905	864	3372	3R	2	7C
* 0202098	4246	333	2474	7K	2	5Q
* 0202098	4847	601	2474	8B	2	7K
* 0202101	4326	852	3372	3A	2	3Q
* 0202101	5186	860	2474	1Z	3	3A
* 0202101	5229	43	2474	3R	2	3B
* 0202101	5477	248	2474	6F	2	3R
* 0202102	4727	921	3372	3A	1	5C
* 0202102	5527	800	2474	8C	1	3A
* 0202103	2550	0	2474	8B	1	7A
* 0202106	2374	0	2474	7J	1	7C
* 0202106	2867	493	2474	5Q	3	3B
* 0202106	3395	528	2472	3B	1	5Q
* 0202107	1273	74	2475	3R	1	
* 0202107	1305	32	2475	6K	3	3R
* 0202108	5255	340	2474	1W	1	3R
* 0202109	5232	1443	2474	6N	1	2N
* 0202111	5749	995	2474	5C	2	7C
* 0202113	4165	382	2474	1Z	3	5Q
* 0202113	5051	886	2474	7K	2	1Z
* 0202116	5367	337	2474	7K	2	7D
* 0202117	3939	1042	2474	5Q	3	1W
* 0202117	4513	25	2374	3R	2	7C
* 0202119	4607	1497	2474	3P	1	7K
* 0202119	4681	74	2474	3D	2	3P
* 0202120	2920	660	3172	5C	2	7C
* 0202120	2994	74	2474	8P	1	5C
* 0202120	3405	411	2474	3T	2	3B
* 0202121	5854	338	3372	3A	3	7C
* 0202122	4950	814	2474	5Q	2	2N
* 0202122	5234	284	2474	8F	2	5Q
* 0202123	6375	266	2474	3T	2	7D
* 0202125	5802	704	2474	7L	2	1Z
* 0202125	6418	616	2474	1Z	3	7L

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202126	6789	1152	2474	3T	1	5Q
* 0202127	5584	291	2474	1Z	3	5G
* 0202127	5830	246	2474	1Z	3	1Z
* 0202127	5990	160	2474	3Q	2	1Z
* 0202127	6790	960	2474	7K	2	1Z
* 0202128	4375	557	3372	1Z	1	5C
* 0202128	4955	580	2474	6N	3	7C
* 0202130	5239	681	2474	1Z	3	3T
* 0202130	7004	84	2474	3T	2	7C
* 0202131	4540	404	2474	3Q	2	7C
* 0202131	6129	998	2474	2N	1	7D
* 0202132	5510	1490	3372	3R	2	2N
* 0202133	3777	560	3372	1Z	3	3R
* 0202134	5203	1115	2474	3Q	1	7K
* 0202137	4753	916	2474	1Z	3	4D
* 0202137	4848	115	3372	5W	1	1Z
* 0202137	5359	3	2474	3P	2	3B
* 0202137	5361	2	2474	3P	2	3P
* 0202137	5361	0	2474	3P	2	3B
* 0202137	5361	0	2474	3P	2	3P
* 0202137	5361	0	2474	3P	2	3B
* 0202138	4726	1389	2474	5Q	3	7C
* 0202138	4766	40	2474	5Q	1	3B
* 0202138	5168	402	2474	6N	2	5Q
* 0202139	4658	404	2474	5Q	2	3Q
* 0202140	2564	393	3372	3A	2	7C
* 0202141	4557	242	2474	6F	2	7C
* 0202141	4946	389	2474	3A	2	6F
* 0202142	5726	850	2474	2N	3	8F
* 0202142	6080	354	3372	2A	1	2N
* 0202143	5175	1026	2474	3P	1	7C
* 0202146	3518	892	2474	5Q	1	2N
* 0202146	3573	55	2474	1W	2	3Q
* 0202146	3575	2	2475	7K	1	3B
* 0202147	5165	761	2474	2F	1	5C
* 0202147	5555	390	2474	2F	1	6F
* 0202149	4595	485	2474	3A	2	7C
* 0202149	5745	1150	3372	3R	3	3W
* 0202150	6417	0	2475	1W	2	7C
* 0202151	4353	467	2474	5D	3	3P
* 0202151	4906	553	2474	7A	1	5D
* 0202154	5606	859	3372	5C	2	7C
* 0202155	4072	143	2474	1Z	1	7C
* 0202155	4836	59	2474	3B	3	3W
* 0202156	6541	0	2475	3B	2	5D
* 0202156	6631	90	2474	5W	2	3B
* 0202156	6739	108	2474	5W	2	5W

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202157	3418	212	2474	8B	1	7G
* 0202157	4566	1148	2474	5Q	1	8B
* 0202158	5234	202	2474	3Q	1	5C
* 0202158	5522	288	2474	2N	3	3B
* 0202160	4784	567	2474	8P	2	7C
* 0202160	4818	34	2474	3T	2	5W
* 0202160	4880	62	2474	5Q	2	3T
* 0202161	4515	653	2474	1Z	3	3W
* 0202161	5472	957	2474	3Q	2	1Z
* 0202163	3395	380	2474	3R	2	7C
* 0202164	5017	337	3372	3A	2	7C
* 0202164	6124	1107	2474	1Z	3	3A
* 0202164	6622	498	2474	4R	1	3B
* 0202166	4009	250	2474	3Q	2	7C
* 0202166	5124	1115	2474	3B	1	3Q
* 0202167	4022	937	2474	1W	2	5Q
* 0202167	4492	470	2474	5Q	1	3T
* 0202167	4898	406	2474	1T	3	5Q
* 0202168	608	0	3172	3R	1	4D
* 0202169	4511	0	2474	5Q	2	5Q
* 0202169	4625	114	2474	1Z	1	5Q
* 0202169	6178	1011	2474	6N	2	6A
* 0202171	4182	362	3372	3A	2	7K
* 0202171	4660	478	2474	7K	3	3A
* 0202171	4974	314	2474	1Z	2	7K
* 0202171	4994	20	2474	8F	2	1Z
* 0202171	5063	69	2474	2N	2	8F
* 0202172	5743	355	3372	3R	1	7D
* 0202173	3010	1030	2474	5Q	1	2C
* 0202173	3300	290	2474	5Q	1	5Q
* 0202173	3365	65	2474	3T	2	5Q
* 0202173	4089	724	3372	3R	2	3T
* 0202174	5997	1360	2474	5C	3	7C
* 0202176	4008	11	2474	2N	3	1Z
* 0202178	5254	1062	2474	5C	3	4D
* 0202179	4201	101	2474	3M	2	3W
* 0202181	5997	1513	2474	5Q	1	7C
* 0202181	6927	930	2474	8B	2	5Q
* 0202182	6570	1336	2474	3M	3	7C
* 0202182	6822	252	2474	1Z	1	7C
* 0202183	5624	1430	3372	1Z	1	5C
* 0202185	3979	0	2475	2A	2	3Q
* 0202185	5221	1242	3372	3R	2	5D
* 0202185	5221	0	2474	8B	1	3R
* 0202186	4357	381	2474	2N	2	1Z
* 0202186	4361	4	2474	5Q	2	7C
* 0202186	4459	98	3372	3A	3	5Q

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Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202186	5228	157	2474	3T	2	7C
* 0202188	5474	1373	2474	2N	1	5C
* 0202188	6122	648	2474	1Z	2	2N
* 0202189	5280	652	2474	5Q	1	7C
* 0202192	5169	1932	2474	2N	1	5C
* 0202192	5867	698	2474	1Z	1	1W
* 0202195	4615	727	2474	7K	2	7C
* 0202196	4275	1105	2474	5W	3	3D
* 0202197	5577	1116	2474	3Q	3	7K
* 0202197	5766	189	3372	3R	2	7D
* 0202201	4643	1482	2474	5Q	3	6A
* 0202201	5568	925	2474	5Q	1	5Q
* 0202203	3448	679	2474	1Z	1	3Q
* 0202203	3495	47	2474	5W	2	1Z
* 0202203	4823	496	2474	3T	2	7C
* 0202204	5260	804	2474	5B	3	2S
* 0202204	6388	1128	3374	2Q	1	5B
* 0202205	4933	914	3372	1Z	1	5G
* 0202205	5163	230	2474	8F	1	1Z
* 0202206	3892	57	2474	3P	2	3P
* 0202206	5359	30	2474	3T	2	6A
* 0202207	5319	434	2474	1Z	3	5Q
* 0202208	4624	688	2474	6Q	3	5B
* 0202208	4649	25	2474	3R	2	6Q
* 0202208	5348	699	2474	8B	3	3Q
* 0202209	4521	401	2474	6P	2	7C
* 0202209	4521	0	2474	3R	1	6P
* 0202210	4294	1170	2474	1A	3	5G
* 0202210	4489	195	2474	5C	2	1A
* 0202211	3413	62	2474	3U	3	8F
* 0202211	4099	218	2474	1Z	2	7D
* 0202211	4489	390	2474	7A	2	1Z
* 0202212	5383	320	2474	2N	2	7C
* 0202212	5881	498	3372	3R	1	2N
* 0202213	5521	1316	2474	6F	1	1Z
* 0202213	5868	347	2474	1A	2	3B
* 0202214	5431	459	2474	3T	1	7D
* 0202217	5282	323	2474	6J	2	7C
* 0202217	5476	194	2474	3B	2	6K
* 0202219	4854	785	2474	3R	2	5G
* 0202220	2913	315	2474	1Z	2	1Z
* 0202220	3029	116	2474	3M	1	1Z
* 0202220	3760	731	2474	8F	2	7C
* 0202223	6509	0	2475	6J	2	3T
* 0202223	6626	117	2474	3R	3	6Y
* 0202223	7040	414	3372	3A	3	3R
* 0202223	7140	100	2474	3T	1	3R

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Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202224	5164	902	3372	1Z	1	3Q
* 0202224	5764	600	3372	3R	1	1Z
* 0202225	7240	1092	2474	7A	1	7D
* 0202226	3405	361	3372	3A	3	3W
* 0202226	4554	1149	2474	3T	3	3A
* 0202227	5467	958	2474	1Z	3	7H
* 0202227	5667	200	2474	6N	2	3Q
* 0202227	5927	460	2474	3R	2	3Q
* 0202228	5768	817	2474	6F	3	3W
* 0202228	5868	100	2474	7A	2	6F
* 0202229	3871	399	2474	5Q	3	3Q
* 0202229	4097	226	3372	1W	3	5Q
* 0202231	4851	1179	3372	3A	3	7K
* 0202231	5378	527	3372	3R	1	3R
* 0202232	5412	1514	3372	3A	2	1Z
* 0202232	6418	1007	2474	5Q	1	3R
* 0202233	5394	1370	2474	1W	1	3Q
* 0202233	5439	45	2474	5D	2	3T
* 0202233	5634	195	2474	8C	2	3Q
* 0202234	3815	190	2474	1Z	1	1Z
* 0202234	4121	306	2474	1W	3	3W
* 0202234	4206	85	2474	5Q	2	3T
* 0202235	5045	832	2474	2S	3	3R
* 0202235	5050	1	2474	5Q	1	3D
* 0202236	5812	1350	2474	7J	1	7D
* 0202236	7010	1198	2474	3T	2	1B
* 0202237	4470	66	2474	2S	2	7C
* 0202239	4367	896	2474	5W	1	5C
* 0202239	4595	228	2474	9J	1	5W
* 0202239	5286	691	2474	6F	2	9J
* 0202241	4777	510	3372	3A	2	7C
* 0202241	4981	204	2474	5Q	1	8B
* 0202241	5365	384	2474	3T	2	6A
* 0202242	6240	1456	2474	1Z	2	7C
* 0202244	4892	401	2474	4P	3	3D
* 0202245	4226	0	2474	2S	2	7C
* 0202247	3621	879	2474	3Q	2	7C
* 0202248	4340	865	3372	1Z	1	7K
* 0202248	5183	843	2474	7K	1	1Z
* 0202250	4946	733	2474	5Q	3	7C
* 0202250	5015	69	2474	5Q	2	5Q
* 0202251	2661	169	2474	4P	2	4B
* 0202252	4334	1447	3372	3R	1	7K
* 0202254	5922	149	2474	5Q	2	7C
* 0202256	5258	216	2474	6J	2	7D
* 0202257	6791	790	2474	3T	2	7C
* 0202259	3098	304	2474	1Z	2	1Z

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202259	3994	896	2474	3Q	2	1Z
* 0202260	5618	1175	2474	8C	2	7C
* 0202260	6536	918	2474	1Z	1	7C
* 0202260	6901	365	2474	3T	1	1Z
* 0202260	6901	0	2474	7K	2	3T
* 0202260	6901	0	2374	6R	2	7K
* 0202261	5025	436	2474	2S	2	3Q
* 0202261	6696	1212	2474	1W	1	7D
* 0202262	5036	696	2474	3Q	1	3P
* 0202262	5036	0	2474	3P	1	6F
* 0202262	5445	409	2474	3M	2	3P
* 0202262	5446	1	2474	3P	2	3B
* 0202263	5772	530	2474	1Z	2	7C
* 0202264	4124	78	2474	3Q	1	3B
* 0202264	5453	227	2474	3R	2	7C
* 0202265	4522	667	2474	5Q	1	7K
* 0202265	4890	368	2474	5Q	1	3B
* 0202265	5161	271	2474	5Q	2	7K
* 0202266	3218	882	2474	3P	1	4J
* 0202266	3557	339	2474	1G	2	3B
* 0202267	5742	385	2474	3Q	3	4M
* 0202267	5753	11	2474	7K	1	6P
* 0202267	6593	840	2474	3R	2	3T
* 0202268	5627	1199	2474	1Z	1	3R
* 0202269	3912	332	2474	5Q	1	7C
* 0202269	4479	567	3372	6Q	2	5Q
* 0202271	5791	20	2474	5C	3	3W
* 0202271	5990	199	2474	5Q	1	5C
* 0202272	3895	0	2475	3Q	1	7C
* 0202272	5712	883	2474	3R	1	7D
* 0202272	5904	192	2474	1Z	2	3R
* 0202273	5078	1291	3372	3A	2	3W
* 0202274	3766	246	2474	1G	2	7C
* 0202276	6324	439	3372	3R	2	7C
* 0202278	5425	946	2474	2N	1	7C
* 0202278	5470	45	2474	3Q	2	2N
* 0202278	5485	15	2474	8F	1	3Q
* 0202280	3762	355	2474	3A	2	7C
* 0202280	3968	206	2474	6F	1	3A
* 0202280	4499	0	2474	2F	2	6A
* 0202281	4928	1555	3372	3A	3	5Q
* 0202281	4939	11	2474	8P	3	3A
* 0202281	5954	1015	2474	1Z	2	6A
* 0202282	5246	2	2474	4P	1	3R
* 0202282	6497	0	2474	3R	2	7C
* 0202283	3718	570	2474	2S	1	7C
* 0202283	3725	7	2474	5W	1	3B

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202283	4243	518	3372	3A	2	5W
* 0202284	4160	399	2474	2N	1	5C
* 0202285	5401	1249	2474	3D	2	1Z
* 0202285	6771	1370	2474	5C	2	3D
* 0202286	1868	0	2474	7K	2	1Z
* 0202288	4211	934	2474	3T	1	5G
* 0202288	4696	485	2474	1W	2	5Q
* 0202289	5497	661	2474	8F	1	4B
* 0202290	4214	422	2474	3R	1	7D
* 0202290	4585	371	2474	3Q	2	3R
* 0202290	4812	227	2474	5Q	1	3Q
* 0202290	5430	618	2474	5Q	2	5Q
* 0202291	4146	816	2474	3R	1	7C
* 0202291	5302	1153	2474	1W	3	5C
* 0202292	6532	802	2474	5W	1	7D
* 0202293	4634	438	2474	1Z	1	8F
* 0202293	4788	154	2474	1Z	2	1Z
* 0202293	5399	611	2474	5Q	1	1Z
* 0202294	3863	988	2474	5Q	3	7C
* 0202294	4063	200	2174	5Q	1	5Q
* 0202294	4750	887	2474	6N	1	5Q
* 0202296	5268	778	2474	5B	1	4P
* 0202296	5765	1275	2474	8F	1	4P
* 0202297	5190	492	2474	1W	2	7C
* 0202298	4227	521	2474	3M	1	2N
* 0202298	4295	68	3372	3A	2	7D
* 0202299	5315	483	2474	6F	2	5G
* 0202299	5795	480	2474	7K	1	6F
* 0202300	3956	862	2474	1Z	1	2S
* 0202300	4363	407	2474	3D	2	1Z
* 0202301	3042	1007	2474	7K	3	7D
* 0202301	3196	154	2474	6N	1	3B
* 0202302	5082	211	2474	1G	3	5C
* 0202304	3304	290	2474	1Z	1	7C
* 0202304	4322	771	2474	2N	2	7D
* 0202305	4349	391	2474	3Q	1	6F
* 0202305	5087	738	2474	5Q	3	5C
* 0202306	3383	113	2474	1Z	1	1Z
* 0202306	3921	538	2474	3D	2	1Z
* 0202306	4377	456	2374	1Z	1	7C
* 0202307	5843	1157	2474	3Q	2	7C
* 0202308	4269	0	2475	2Q	1	2C
* 0202308	4541	272	2474	1Z	3	2Q
* 0202308	4724	183	2474	5W	1	1Z
* 0202311	3752	27	2474	5C	3	3R
* 0202312	3465	216	2474	6Q	2	7C
* 0202312	4022	557	2474	2N	1	3Q

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202313	6150	391	2474	7E	2	7D
* 0202315	4097	357	2474	3T	2	7C
* 0202315	4492	241	2474	6N	2	3B
* 0202317	4173	373	2474	8B	2	7C
* 0202317	4238	65	2474	1W	2	3R
* 0202317	4318	80	2474	5C	2	1W
* 0202319	4970	268	2474	1Z	2	1Z
* 0202319	5303	333	2474	3B	1	1Z
* 0202319	5638	335	2474	5Q	2	5Q
* 0202321	4974	529	2474	7K	2	7C
* 0202321	5074	99	2474	1Z	3	3T
* 0202322	4100	189	2474	5Q	2	7C
* 0202322	5098	998	2474	1Z	2	5Q
* 0202322	5675	577	2474	5W	2	1Z
* 0202323	4638	392	2474	8P	1	8C
* 0202324	3986	860	2474	5C	3	8F
* 0202325	5554	1056	2474	8F	1	7D
* 0202326	4403	448	3372	3A	3	7K
* 0202326	5083	3	2474	3T	2	7D
* 0202327	6609	513	2474	4R	2	7D
* 0202327	6781	172	2474	7K	2	4R
* 0202328	2225	394	2474	3R	2	7C
* 0202328	3381	635	2474	5C	2	7C
* 0202330	5157	662	2474	1Z	1	7C
* 0202331	3163	421	3372	3A	2	5D
* 0202331	3163	0	2374	4A	3	3A
* 0202331	4214	259	2474	1Z	2	7C
* 0202333	4442	1121	2474	5Q	1	7C
* 0202333	4966	524	2474	8B	2	5Q
* 0202333	5292	326	2474	3T	2	7C
* 0202334	5644	213	2474	2N	2	7D
* 0202336	4776	179	2474	8F	3	5Q
* 0202336	5155	15	2474	3Q	2	7C
* 0202336	5380	225	3372	3A	1	3Q
* 0202338	3678	0	2475	7K	2	7C
* 0202338	3987	309	2474	8C	2	7K
* 0202338	4494	507	2474	2C	1	2C
* 0202339	6364	470	2474	3P	2	7D
* 0202340	4595	227	2474	5W	1	5C
* 0202340	4615	20	2474	2Q	2	5W
* 0202340	4619	4	2474	1W	2	4B
* 0202340	4860	221	2474	3M	2	3T
* 0202342	2825	42	2474	6T	2	7E
* 0202342	2827	2	2474	7K	2	6T
* 0202342	3497	670	2474	5Q	3	7K
* 0202342	3497	0	2475	2A	2	5Q
* 0202342	3540	43	2474	3R	1	5Q

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202343	5630	893	2474	3T	1	3R
* 0202345	5658	1413	2474	3R	1	7C
* 0202346	4314	19	2474	5W	2	7C
* 0202346	4315	1	2474	5W	2	5W
* 0202346	4799	484	2474	3Q	2	5W
* 0202347	3610	492	2474	2N	3	7C
* 0202347	4196	586	2474	6Q	2	2N
* 0202348	4555	96	2474	7K	2	5D
* 0202348	5945	1390	3374	3R	1	7K
* 0202351	5172	1097	2474	8C	1	1G
* 0202351	6349	1177	2474	1T	2	8C
* 0202353	5541	1062	2474	3Q	1	7C
* 0202353	6591	1050	2474	1G	2	3Q
* 0202354	4883	1450	3372	1Z	2	6F
* 0202354	5488	605	2474	8F	3	1Z
* 0202355	4491	1	2474	3Q	2	7C
* 0202355	5522	1031	2474	7K	2	3Q
* 0202355	5904	382	2474	1Z	2	7C
* 0202356	4456	581	2474	3Q	2	7C
* 0202356	4658	202	2474	1G	1	5D
* 0202356	4973	315	3372	1Z	2	6Q
* 0202356	5772	799	2474	3T	1	1Z
* 0202356	5801	29	2474	3T	2	3T
* 0202358	5207	310	3372	8P	2	7C
* 0202359	4736	355	2474	8C	1	7D
* 0202359	4748	12	2474	3T	2	5D
* 0202360	3352	193	2474	1G	1	1Z
* 0202360	3546	387	2474	3P	1	1Z
* 0202360	4101	555	3372	3R	3	3W
* 0202361	3295	484	2474	1W	2	7C
* 0202362	4576	819	2474	3Q	3	3R
* 0202363	4001	888	2474	1Z	1	5C
* 0202363	4280	279	2474	7K	2	1Z
* 0202363	5024	274	2474	5Q	2	7C
* 0202363	5610	586	2474	5C	2	3B
* 0202364	5343	1084	2474	6J	2	2N
* 0202364	5395	52	2174	5Q	1	7D
* 0202364	5398	55	2474	5Q	1	7D
* 0202365	6022	745	2474	6J	3	8C
* 0202365	6362	340	2474	6N	1	6J
* 0202365	6385	23	2474	1A	1	3A
* 0202366	4428	56	2474	2C	1	5D
* 0202366	4968	540	2474	5Q	2	3Q
* 0202367	4118	46	2474	8C	2	1Z
* 0202367	4201	83	2474	1G	1	8C
* 0202368	3690	176	2474	5C	2	7C
* 0202368	4447	757	2474	1W	2	5C

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202369	5314	299	2474	3Q	2	7D
* 0202370	4750	263	2474	6F	3	3R
* 0202370	5368	618	2474	3T	2	6F
* 0202373	3958	333	2474	1G	2	7C
* 0202373	4975	63	2474	3T	2	7C
* 0202373	5046	71	3372	3R	1	3T
* 0202374	3838	1018	2474	5Q	3	3W
* 0202374	3870	32	2474	5Q	2	5Q
* 0202375	5367	806	2474	6P	2	1Z
* 0202375	5946	579	2474	3T	1	3T
* 0202376	5435	188	2474	8C	2	7D
* 0202377	3701	609	2474	3Q	2	7C
* 0202377	4178	477	2474	3P	1	3Q
* 0202377	4178	0	2474	7K	1	3P
* 0202377	4469	291	2474	2S	1	1G
* 0202378	4138	230	2474	3Q	2	5Q
* 0202378	5079	941	2474	3Q	2	3Q
* 0202379	3804	1617	2474	2C	2	3Q
* 0202380	4716	953	2474	1Z	2	5D
* 0202380	5144	428	2474	8P	2	1Z
* 0202380	5910	766	2474	6E	1	3T
* 0202383	4488	704	2474	1Z	3	7L
* 0202383	4497	9	2474	6F	1	1Z
* 0202384	4630	1218	2474	2N	3	1Z
* 0202384	4902	272	2474	7K	1	1W
* 0202385	4840	786	2474	7K	1	7D
* 0202386	4520	126	2474	1Z	2	1Z
* 0202386	4539	19	2474	2A	2	1Z
* 0202386	5726	1187	2474	3B	2	4B
* 0202388	4824	638	2474	1Z	2	7D
* 0202390	4825	347	2474	7A	2	7C
* 0202391	3575	417	2474	4P	1	3Q
* 0202391	4207	632	2474	7K	1	4A
* 0202391	4628	421	2474	5D	2	7K
* 0202392	2619	55	2475	3R	3	1Z
* 0202393	4800	667	2474	1Z	2	7L
* 0202393	5032	232	2474	6J	2	1Z
* 0202393	5037	237	2474	3D	2	1Z
* 0202393	5040	3	2474	3D	2	3D
* 0202394	3561	1063	2474	2N	2	7C
* 0202394	3800	239	3372	1Z	1	1W
* 0202397	2146	215	2474	3T	2	3Q
* 0202397	3119	973	3372	3R	2	3T
* 0202398	4720	1598	2474	3R	3	7C
* 0202398	4898	178	2174	5Q	2	3R
* 0202398	5212	492	3372	3R	2	3R
* 0202399	3930	291	2474	6N	2	6F

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202400	5271	808	2474	6N	2	7D
* 0202401	4167	305	3372	3A	1	7D
* 0202401	4803	26	2474	3P	1	7C
* 0202401	4855	52	2474	3R	2	3B
* 0202402	5027	2128	2474	1Z	1	3Q
* 0202402	5474	447	2474	8F	1	3U
* 0202402	5671	197	2474	2S	3	2N
* 0202403	4299	1165	2474	3T	3	7D
* 0202403	5027	728	2474	3R	2	3Q
* 0202404	5064	509	2474	5B	2	7C
* 0202404	5107	43	2474	2N	1	5B
* 0202405	3679	240	2474	2N	1	3B
* 0202406	3635	830	2474	1Z	1	5C
* 0202406	3650	15	2474	7K	1	1Z
* 0202406	4216	566	2474	1Z	3	7K
* 0202406	4430	214	2474	6F	2	1Z
* 0202407	6998	273	2474	5Q	2	7D
* 0202409	5098	691	2474	8B	1	6Q
* 0202409	5845	747	2474	7L	2	8B
* 0202410	4463	1176	3372	3A	2	3Q
* 0202410	5639	3	2474	3T	1	3B
* 0202412	4616	1613	3372	3A	1	7K
* 0202413	5031	523	2474	1Z	1	7C
* 0202413	5033	2	2474	3B	2	3B
* 0202415	4755	435	2474	6C	2	1Z
* 0202416	4863	387	2474	6J	2	7C
* 0202417	4806	1164	3372	3A	1	7C
* 0202419	1873	686	2474	1W	2	7C
* 0202419	1921	48	2474	1W	2	1W
* 0202419	2413	492	2474	6N	3	1W
* 0202420	4405	226	2474	7K	1	5C
* 0202420	4899	494	2474	6F	2	3Q
* 0202421	4244	798	2474	5Q	1	7D
* 0202423	4232	1399	2474	5C	1	6Q
* 0202424	4268	785	2474	8C	3	7C
* 0202424	4511	243	2474	1W	2	7D
* 0202424	4980	469	2474	5W	1	2N
* 0202426	5476	1008	2474	3T	2	7C
* 0202426	5523	47	2374	3A	1	3T
* 0202427	4540	345	2474	2N	1	1Z
* 0202427	5253	13	2474	1G	1	7C
* 0202428	3119	162	2474	3Q	2	3Q
* 0202428	3635	516	3372	6Q	2	3Q
* 0202431	3949	441	2474	1G	2	5G
* 0202432	4527	1379	2474	3Q	1	5D
* 0202432	4573	46	2474	1Z	2	5D
* 0202433	3892	1157	3372	3A	2	5Q

APPENDIX A. FILTERED ENGINE REMOVAL DATA

Engine Serial Number	Flight Hours Since New	Flight Hours Since Last Repair	Star Status Code	Reason for Removal	Degree Last Repair	Prior Removal Reason
* 0202437	4948	313	2474	6F	3	5D
* 0202437	5018	70	2474	3R	2	6F
* 0202437	5398	380	2474	3R	2	3R
* 0202438	5418	1419	2474	5W	1	5C
* 0202439	4403	811	2474	3Q	1	6O
* 0202439	4552	149	3372	1Z	2	3Q
* 0202439	5405	853	2474	6F	1	1Z
* 0202440	4588	116	2474	4P	3	6Q
* 0202440	5149	561	2474	7A	1	4P
* 0202441	4799	0	2474	5Q	2	5G
* 0202441	5946	559	3372	1Z	1	7C
* 0202442	5080	1279	2474	1G	1	6Q
* 0202443	5347	1362	3372	3A	1	5C
* 0202443	5445	98	2474	7K	1	3R
* 0202443	5642	197	2474	7J	3	7K
* 0202444	4656	37	2474	1Z	3	7D
* 0202444	4660	4	2474	1Z	2	1Z
* 0202444	5171	511	2474	5W	2	1Z

APPENDIX B. FIVE-YEAR TIME BETWEEN FAILURES DATA BASE

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
1	0	52	2	103	32	154	78	205	163
2	0	53	3	104	33	155	79	206	168
3	0	54	3	105	34	156	80	207	168
4	0	55	3	106	35	157	81	208	169
5	0	56	3	107	35	158	82	209	170
6	0	57	3	108	37	159	82	210	172
7	0	58	3	109	39	160	83	211	176
8	0	59	3	110	40	161	83	212	178
9	0	60	3	111	40	162	84	213	178
10	0	61	3	112	40	163	85	214	178
11	0	62	4	113	42	164	88	215	179
12	0	63	4	114	43	165	89	216	183
13	0	64	4	115	43	166	89	217	188
14	0	65	5	116	43	167	90	218	189
15	0	66	5	117	44	168	96	219	189
16	0	67	6	118	45	169	98	220	190
17	0	68	7	119	45	170	98	221	192
18	0	69	7	120	46	171	99	222	193
19	0	70	9	121	46	172	99	223	194
20	0	71	10	122	47	173	100	224	195
21	0	72	11	123	47	174	100	225	195
22	0	73	11	124	48	175	101	226	197
23	0	74	11	125	51	176	105	227	197
24	0	75	11	126	52	177	108	228	199
25	0	76	11	127	52	178	113	229	199
26	0	77	12	128	55	179	114	230	200
27	0	78	13	129	55	180	115	231	200
28	0	79	14	130	55	181	115	232	202
29	0	80	15	131	56	182	116	233	202
30	0	81	15	132	57	183	116	234	204
31	0	82	15	133	59	184	116	235	206
32	0	83	15	134	62	185	117	236	210
33	0	84	15	135	62	186	120	237	211
34	0	85	16	136	63	187	122	238	211
35	0	86	18	137	65	188	126	239	212
36	0	87	19	138	65	189	129	240	213
37	0	88	19	139	66	190	130	241	214
38	0	89	20	140	67	191	138	242	215
39	0	90	20	141	67	192	140	243	216
40	1	91	20	142	67	193	143	244	216
41	1	92	20	143	67	194	143	245	217
42	1	93	22	144	68	195	149	246	218
43	1	94	23	145	69	196	149	247	221
44	1	95	25	146	69	197	151	248	221
45	2	96	25	147	70	198	154	249	225
46	2	97	26	148	70	199	154	250	225
47	2	98	27	149	71	200	155	251	226
48	2	99	29	150	74	201	157	252	226
49	2	100	30	151	74	202	160	253	226
50	2	101	31	152	74	203	161	254	227
51	2	102	32	153	75	204	162	255	227

APPENDIX B. FIVE-YEAR TIME BETWEEN FAILURES DATA BASE

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
256	227	307	302	358	381	409	456	460	533
257	228	308	304	359	382	410	459	461	538
258	228	309	305	360	382	411	460	462	540
259	229	310	306	361	384	412	460	463	553
260	230	311	309	362	384	413	465	464	555
261	230	312	310	363	385	414	465	465	555
262	232	313	310	364	385	415	467	466	557
263	232	314	313	365	387	416	469	467	557
264	236	315	314	366	387	417	470	468	559
265	237	316	315	367	389	418	470	469	560
266	239	317	315	368	390	419	477	470	561
267	240	318	320	369	390	420	478	471	563
268	241	319	320	370	391	421	480	472	566
269	241	320	322	371	391	422	480	473	567
270	242	321	323	372	392	423	482	474	567
271	243	322	326	373	393	424	483	475	570
272	246	323	326	374	394	425	484	476	573
273	246	324	327	375	399	426	484	477	577
274	248	325	332	376	399	427	485	478	579
275	249	326	333	377	401	428	485	479	579
276	250	327	333	378	401	429	485	480	580
277	251	328	333	379	402	430	490	481	581
278	251	329	335	380	404	431	491	482	586
279	252	330	337	381	404	432	492	483	586
280	259	331	337	382	405	433	492	484	592
281	262	332	338	383	406	434	492	485	595
282	263	333	338	384	406	435	492	486	596
283	266	334	339	385	407	436	493	487	596
284	268	335	340	386	409	437	494	488	600
285	271	336	340	387	411	438	496	489	601
286	271	337	345	388	414	439	498	490	605
287	272	338	346	389	415	440	498	491	609
288	272	339	347	390	417	441	504	492	611
289	272	340	347	391	421	442	507	493	614
290	273	341	354	392	421	443	508	494	615
291	274	342	355	393	422	444	509	495	615
292	279	343	355	394	422	445	510	496	616
293	279	344	355	395	423	446	511	497	618
294	284	345	356	396	424	447	513	498	618
295	288	346	357	397	427	448	516	499	632
296	290	347	358	398	428	449	516	500	635
297	290	348	361	399	434	450	517	501	638
298	291	349	362	400	435	451	518	502	640
299	291	350	362	401	436	452	521	503	648
300	291	351	365	402	436	453	523	504	652
301	293	352	368	403	438	454	524	505	653
302	293	353	371	404	439	455	527	506	656
303	294	354	373	405	441	456	528	507	659
304	299	355	376	406	447	457	529	508	660
305	299	356	380	407	448	458	529	509	661
306	301	357	380	408	450	459	530	510	662

APPENDIX B. FIVE-YEAR TIME BETWEEN FAILURES DATA BASE

Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times	Index	Fail Times
511	667	562	811	613	975	664	1165	715	1513
512	667	563	814	614	988	665	1170	716	1514
513	668	564	816	615	989	666	1175	717	1555
514	670	565	817	616	994	667	1176	718	1598
515	679	566	819	617	995	668	1177	719	1613
516	681	567	822	618	998	669	1179	720	1617
517	685	568	830	619	998	670	1183	721	1638
518	686	569	832	620	998	671	1187	722	1932
519	688	570	840	621	1006	672	1198	723	2128
520	688	571	843	622	1007	673	1199		
521	691	572	850	623	1007	674	1212	Total	346802
522	691	573	852	624	1008	675	1212		
523	692	574	853	625	1011	676	1218		
524	696	575	859	626	1015	677	1235		
525	698	576	860	627	1018	678	1242		
526	699	577	860	628	1018	679	1249		
527	703	578	862	629	1026	680	1275		
528	704	579	864	630	1030	681	1279		
529	704	580	865	631	1030	682	1282		
530	722	581	879	632	1031	683	1283		
531	724	582	882	633	1042	684	1285		
532	727	583	883	634	1050	685	1291		
533	728	584	886	635	1056	686	1316		
534	731	585	887	636	1062	687	1320		
535	733	586	888	637	1062	688	1327		
536	738	587	892	638	1063	689	1336		
537	738	588	893	639	1066	690	1350		
538	745	589	896	640	1084	691	1353		
539	747	590	896	641	1089	692	1354		
540	747	591	902	642	1092	693	1360		
541	747	592	912	643	1096	694	1362		
542	757	593	914	644	1097	695	1370		
543	761	594	916	645	1100	696	1370		
544	761	595	918	646	1103	697	1373		
545	766	596	921	647	1105	698	1379		
546	770	597	925	648	1107	699	1389		
547	771	598	927	649	1115	700	1390		
548	778	599	930	650	1115	701	1399		
549	785	600	934	651	1116	702	1413		
550	785	601	937	652	1121	703	1419		
551	786	602	939	653	1126	704	1423		
552	790	603	941	654	1128	705	1430		
553	791	604	942	655	1135	706	1441		
554	798	605	946	656	1148	707	1443		
555	799	606	953	657	1149	708	1447		
556	800	607	954	658	1150	709	1450		
557	802	608	957	659	1152	710	1456		
558	804	609	958	660	1153	711	1470		
559	806	610	959	661	1157	712	1482		
560	808	611	960	662	1157	713	1490		
561	809	612	973	663	1164	714	1497		

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0201021	3840	481	4D						
* 0201021	3870	511	3W						30
* 0201021	3883	524	4D			13			
* 0201021	3893	534	7C					10	
* 0201022	3100	24	3W						
* 0201022	3115	39	8P	5					
* 0201022	3155	79	3W						
* 0201022	3538	462	3W			383			
* 0201022	3549	473	3W			11			
* 0201102	5200	52	3W						
* 0201102	5236	88	1Z	36					
* 0201104	5166	0	3W						
* 0201104	5327	161	6N	161					
* 0201104	5430	103	3W						
* 0201104	6416	1089	3R	986					
* 0201106	5799	960	3W						
* 0201106	5833	994	2N	34					
* 0201106	6116	253	4D						
* 0201106	6419	556	7C					303	
* 0201108	4576	185	3W						
* 0201108	5020	629	7C		444				
* 0201108	5129	109	3W						
* 0201108	5318	298	4D			189			
* 0201108	5485	465	5Q				167		
* 0201111	5281	13	3W						
* 0201111	5539	271	7A	258					
* 0201111	6136	241	4D						
* 0201111	6136	241	3R				0		
* 0201112	5804	615	3W						
* 0201112	5804	615	3Q	0					
* 0201113	5162	111	3W						
* 0201113	5281	230	3W			119			
* 0201113	5313	262	1Z	32					
* 0201116	4486	0	3W						
* 0201116	4874	388	3W			388			
* 0201116	5021	535	3W			147			
* 0201116	5034	548	7K	13					
* 0201116	5034	0	3W						
* 0201116	5155	121	3W			121			
* 0201116	5245	211	3W			90			
* 0201116	6067	1033	7C		822				
* 0201119	5189	536	3W						
* 0201119	5247	594	7C		58				
* 0201120	4930	1744	3W						
* 0201120	5026	1840	7D		96				
* 0201120	5041	0	4D						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0201120	5041	0	6Q				0		
* 0201120	5088	47	3W						
* 0201120	5131	90	3W			43			
* 0201120	5464	423	3R	333					
* 0201121	2591	1101	3W						
* 0201121	2740	1250	3W			149			
* 0201121	2913	1423	5Q	173					
* 0201123	4723	180	3W						
* 0201123	4878	335	3W			155			
* 0201123	4930	387	3W			52			
* 0201123	4946	403	4D			16			
* 0201123	4958	415	7C					12	
* 0201124	1421	20	3W						
* 0201124	1582	181	3W			161			
* 0201124	1610	209	3W			28			
* 0201124	1986	585	3W			376			
* 0201124	2360	959	1G	374					
* 0201124	2800	43	3W						
* 0201124	2920	163	3R	120					
* 0201125	4018	92	3W						
* 0201125	4496	570	7C		478				
* 0201127	4231	0	3W						
* 0201127	4525	294	4M	294					
* 0201127	4826	1	4D						
* 0201127	4828	3	3D				2		
* 0201128	1942	9	3W						
* 0201128	1945	12	3W			3			
* 0201128	2233	300	3W			288			
* 0201128	2831	898	4D			598			
* 0201128	2888	955	3W						57
* 0201128	3016	1083	7C		128				
* 0202001	4095	366	3W						
* 0202001	5199	1470	3T	1104					
* 0202002	4362	402	3W						
* 0202002	4454	494	4D			92			
* 0202002	4606	646	3W						152
* 0202002	4833	873	3W			227			
* 0202003	6103	827	3W						
* 0202003	6265	989	5Q	162					
* 0202004	5082	0	3W						
* 0202004	5740	658	3W			658			
* 0202004	5774	692	3R	34					
* 0202007	1778	616	4D						
* 0202007	1778	616	7C					0	
* 0202007	1892	114	3W						
* 0202007	1892	114	4D			0			

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202007	2179	401	3W						287
* 0202007	2311	533	3T	132					
* 0202007	2311	0	3W						
* 0202007	2311	0	3W			0			
* 0202007	2562	251	1Z	251					
* 0202008	3165	242	3W						
* 0202008	3454	531	7C		289				
* 0202009	4697	352	3W						
* 0202009	4788	443	4D			91			
* 0202009	4854	509	7C					66	
* 0202009	4979	134	3W						
* 0202009	5251	406	1G	272					
* 0202009	5251	0	3W						
* 0202009	5908	657	7C		657				
* 0202011	3589	421	4D						
* 0202011	3648	480	3W						59
* 0202011	3690	522	5G	42					
* 0202012	4390	243	3W						
* 0202012	4532	385	6E	142					
* 0202012	6234	422	3W						
* 0202012	6559	747	6J	325					
* 0202014	3339	1029	3W			503			
* 0202014	3663.	1353	6N	324					
* 0202015	3893	859	3W						
* 0202015	4350	1316	3W			457			
* 0202015	4361	1327	4D			11			
* 0202015	4361	1327	3A				0		
* 0202016	5204	297	3W						
* 0202016	5411	504	1Z	207					
* 0202018	4356	221	4D						
* 0202018	4359	224	3W						3
* 0202018	4405	270	3W			46			
* 0202020	4116	959	3W						
* 0202020	4258	1101	7C		142				
* 0202020	4278	20	3W						
* 0202020	4687	429	3W			409			
* 0202022	5025	638	3W			209			
* 0202022	5240	853	7C		215				
* 0202023	4851	94	3W						
* 0202023	5504	747	5Q	653					
* 0202027	5258	846	3W						
* 0202027	6039	1627	7C		781				
* 0202027	6384	345	3W						
* 0202027	6795	756	7C		411				
* 0202029	5096	562	3W						
* 0202029	5282	748	3W			186			

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202029	5509	975	2S	227					
* 0202030	4187	341	3W						
* 0202030	4972	1126	5Q	785					
* 0202033	4448	141	3W						
* 0202033	4600	293	3W			152			
* 0202034	3771	842	3W						
* 0202034	4141	1212	3Q	370					
* 0202035	2619	1	3W						
* 0202035	3213	595	3U	594					
* 0202038	3546	922	3W						
* 0202038	3566	942	1Z	20					
* 0202040	4045	385	3W						
* 0202040	4173	513	7C		128				
* 0202040	4456	283	3W						
* 0202040	5012	839	4D			556			
* 0202042	5606	596	4D						238
* 0202042	5606	596	7K				0		
* 0202043	5036	589	4D						
* 0202043	5079	632	7C					43	
* 0202046	6591	661	3W						
* 0202046	6639	709	7C		48				
* 0202047	3116	1219	4D						
* 0202047	3152	1255	3W						36
* 0202047	3159	1262	4D			7			
* 0202047	3302	1405	7D					143	
* 0202048	5509	472	3W						
* 0202048	5976	939	1Z	467					
* 0202049	5184	1318	4D						
* 0202049	5186	1320	4D						2
* 0202049	5186	1320	5Q				0		
* 0202049	5196	10	3W						
* 0202049	5196	10	8P	0					
* 0202049	5456	260	3W						
* 0202049	5468	272	5Q	12					
* 0202051	3451	326	3W						
* 0202051	3599	474	4D			148			
* 0202051	3605	480	4D						6
* 0202051	3605	480	3A				0		
* 0202052	4450	539	3W						
* 0202052	4458	547	3W			8			
* 0202052	4462	551	4D			4			
* 0202052	4466	555	3A				4		
* 0202054	3511	162	4D						
* 0202054	3814	465	3M				303		
* 0202055	5578	191	4D						
* 0202055	6372	985	7C					794	

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202056	3600	1103	3W						
* 0202056	3600	1103	3R	0					
* 0202060	4917	0	3W						
* 0202060	5339	422	3R	422					
* 0202062	5011	547	3W						
* 0202062	5027	563	4D			16			
* 0202062	5027	563	3A				0		
* 0202063	3130	114	3W						
* 0202063	3131	115	3W			1			
* 0202063	3131	115	7K	0					
* 0202064	5630	508	3W						
* 0202064	5829	707	3W			199			
* 0202064	5829	707	7C		0				
* 0202066	4376	1321	3W						
* 0202066	4399	1344	3W			23			
* 0202067	1676	11	3W						
* 0202067	2761	1096	3P	1085					
* 0202068	4261	1422	3W						
* 0202068	4447	1608	7C		186				
* 0202068	4583	136	3W						
* 0202068	4593	146	3W			10			
* 0202068	4683	236	5Q	90					
* 0202069	5017	404	4D						
* 0202069	5071	458	3W						54
* 0202069	5284	671	7C		213				
* 0202071	3765	339	3W						
* 0202071	3765	339	7D		0				
* 0202071	3777	12	3W						
* 0202071	3941	176	3W			164			
* 0202071	3942	177	5Q	1					
* 0202074	4213	655	3W						
* 0202074	4217	659	4D			0			
* 0202074	4217	659	6Q				0		
* 0202074	4266	49	3W						
* 0202074	4867	650	7C		601				
* 0202076	3834	119	3W						
* 0202076	3834	119	7C		0				
* 0202078	3057	81	4D						
* 0202078	3057	81	3R				0		
* 0202081	4545	187	3W						
* 0202081	4631	273	3W			86			
* 0202081	4727	369	3W			96			
* 0202081	5274	916	3W			547			
* 0202081	5641	1283	3R	367					
* 0202084	4981	0	3W						
* 0202084	6179	1198	3W			1198			

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202084	6470	1489	7C		291				
* 0202085	5255	397	3W						
* 0202085	5412	554	4D			157			
* 0202086	2096	16	3W						
* 0202086	2102	22	3W			6			
* 0202086	2147	67	3T	45					
* 0202086	2287	140	3W						
* 0202086	2344	197	4D			57			
* 0202086	2572	217	3W						20
* 0202086	2572	217	6Q	0					
* 0202087	4339	1285	4D						
* 0202087	4339	1285	5Q				0		
* 0202088	4524	608	3W						
* 0202088	4828	912	3R	304					
* 0202089	4435	226	3W						
* 0202089	4435	226	7A	0					
* 0202089	4442	7	3W						
* 0202089	4442	7	7J	0					
* 0202090	3061	0	3W						
* 0202090	3437	376	1Z	376					
* 0202091	3890	1099	3W						
* 0202091	3894	1103	7D		4				
* 0202091	4211	149	3W						
* 0202091	4676	614	2C	465					
* 0202093	4071	161	3W						
* 0202093	4202	292	3W			131			
* 0202093	4482	572	3W			280			
* 0202093	4613	703	3R	131					
* 0202095	5650	45	3W						
* 0202095	5651	46	3W			1			
* 0202095	5694	89	4D			43			
* 0202095	5694	89	1Z				0		
* 0202096	2225	189	3W						
* 0202096	3318	1282	4D			1093			
* 0202096	3318	1282	6R				0		
* 0202097	3421	700	3W						
* 0202097	4004	1283	3W			583			
* 0202097	4043	1322	7C		39				
* 0202097	4905	864	4D						
* 0202097	4905	864	3R				0		
* 0202098	4123	210	4D						
* 0202098	4246	333	7K				123		
* 0202101	4322	848	3W						
* 0202101	4326	852	3A	4					
* 0202101	4457	131	3W						
* 0202101	5186	860	1Z	729					

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202102	4724	918	3W						
* 0202102	4727	921	3A	3					
* 0202102	4775	48	3W						
* 0202102	5060	333	4D			285			
* 0202102	5527	800	8C				467		
* 0202103	2347	1363	4D						
* 0202103	2385	1401	3W						38
* 0202103	2392	1408	4D			7			
* 0202103	2543	1559	3W			151			
* 0202103	2550	1566	7C		7				
* 0202106	2335	923	3W						
* 0202106	2337	925	3W			2			
* 0202106	2374	962	7C		37				
* 0202106	3195	328	4D						
* 0202106	3395	528	4D						200
* 0202106	3395	528	3B				0		
* 0202107	1273	74	4D						
* 0202107	1273	74	3R				0		
* 0202108	4171	267	3W						
* 0202108	4333	429	3W			162			
* 0202108	4508	604	4D			175			
* 0202108	4566	662	7C					58	
* 0202108	4858	292	3W						
* 0202108	4915	349	4D			57			
* 0202109	5019	1230	4D						
* 0202109	5232	1443	6N				213		
* 0202111	4476	247	3W						
* 0202111	4754	525	7C		278				
* 0202112	3728	0	3W						
* 0202112	4926	1198	3W			1198			
* 0202112	4963	1235	3W			37			
* 0202112	5190	1462	3W			227			
* 0202113	4249	84	3W						
* 0202113	4709	544	3W			460			
* 0202113	5051	886	7K	342					
* 0202114	3925	366	3W						
* 0202114	4210	651	4D			285			
* 0202114	4210	651	7C					0	
* 0202117	3939	0	3W						
* 0202117	4314	375	4D			375			
* 0202117	4488	549	7C					174	
* 0202117	4513	25	4D						
* 0202117	4513	25	3R				0		
* 0202118	4954	147	3W						
* 0202118	5171	364	3W			217			
* 0202118	6118	1311	7C		947				

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202121	5454	1070	3W						
* 0202121	5454	1070	4D			0			
* 0202121	5516	1132	7C					62	
* 0202121	5687	171	3W						
* 0202121	5854	338	4D			167			
* 0202121	5854	338	3A				0		
* 0202123	5746	1255	3W						
* 0202123	6109	1618	7D		113				
* 0202125	6036	234	3W						
* 0202125	6418	616	1Z	382					
* 0202126	5621	1546	3W						
* 0202126	5637	1562	5G		16				
* 0202126	6081	444	3W						
* 0202126	6789	1152	3T	708					
* 0202128	4239	421	3W						
* 0202128	4243	425	3W			4			
* 0202128	4364	546	3W			121			
* 0202128	4375	557	4D			11			
* 0202128	4375	557	1Z				0		
* 0202128	4804	429	3W						
* 0202128	4955	580	6N	151					
* 0202129	5267	1477	3W						
* 0202129	5307	1517	7C		40				
* 0202130	4758	200	3W						
* 0202130	5239	681	1Z	481					
* 0202132	4347	327	3W						
* 0202132	5499	1479	3W			1152			
* 0202132	5510	1490	3R	11					
* 0202134	5870	667	4D						
* 0202134	5887	684	7C					17	
* 0202136	4533	170	3W						
* 0202136	4644	281	3W			111			
* 0202136	4681	318	3W			30			
* 0202136	4733	370	7C		52				
* 0202137	4848	115	4D						
* 0202137	4848	115	5W				0		
* 0202138	4765	39	3W						
* 0202138	4766	40	5Q	1					
* 0202140	2561	390	3W						
* 0202140	2564	393	4D			3			
* 0202140	2564	393	3A				0		
* 0202141	4328	13	3W						
* 0202141	4543	228	4D			215			
* 0202141	4557	242	6F				14		
* 0202141	4670	113	3W						
* 0202141	4946	389	3A	276					

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202145	3314	178	3W						
* 0202145	3508	372	4D			194			
* 0202145	3514	378	3W						6
* 0202145	3543	407	4D			29			
* 0202147	5144	740	4D						
* 0202147	5165	761	2F				21		
* 0202149	4595	0	3W						
* 0202149	5675	1080	3W			1080			
* 0202149	5745	1150	4D			70			
* 0202149	5745	1150	3R				0		
* 0202150	6517	0	3W						
* 0202150	6748	231	3W			231			
* 0202150	7042	525	3W			294			
* 0202153	4666	1	3W						
* 0202153	4991	326	3W			325			
* 0202153	5342	677	3W			351			
* 0202154	4694	1073	3W						
* 0202154	4747	1126	7C		53				
* 0202155	4072	0	3W						
* 0202155	4777	705	4D			705			
* 0202155	4777	0	3W						
* 0202155	4836	59	3B	59					
* 0202156	5689	958	4D						
* 0202156	6360	1629	7C					671	
* 0202158	5234	0	3W						
* 0202158	5489	255	3W			255			
* 0202158	5522	288	2N	33					
* 0202161	4854	339	3W						
* 0202161	5472	957	3Q	618					
* 0202162	6255	0	3W						
* 0202162	6314	59	3W			59			
* 0202162	6342	87	3W			21			
* 0202163	2813	356	4D			269			
* 0202163	3015	558	5G					202	
* 0202163	3231	216	3W						
* 0202163	3258	243	3W			27			
* 0202163	3395	380	3R	137					
* 0202164	4930	250	3W						
* 0202164	5017	337	3A	87					
* 0202164	5998	981	3W						
* 0202164	6124	1107	1Z	126					
* 0202166	3428	191	3W						
* 0202166	3439	202	3W			11			
* 0202166	3491	254	3W			52			
* 0202166	3687	450	4D						
* 0202166	3759	522	7C					72	

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202167	3517	432	3W						
* 0202167	3654	569	3W			137			
* 0202167	4022	937	1W	368					
* 0202169	4511	0	3W						
* 0202169	4625	114	1Z	114					
* 0202169	5198	31	3W						
* 0202169	5822	655	4D			624			
* 0202169	6178	1011	6N				356		
* 0202171	4147	327	3W						
* 0202171	4182	362	4D			35			
* 0202171	4182	362	3A				0		
* 0202171	4352	170	3W						
* 0202171	4660	478	7K	308					
* 0202172	4546	65	4D						
* 0202172	5388	907	7C					842	
* 0202172	5743	355	4D						
* 0202172	5743	355	3R				0		
* 0202174	5451	814	3W						
* 0202174	5921	1284	3W			470			
* 0202174	6001	4	3W						
* 0202174	6077	80	3W			76			
* 0202174	6077	80	6A	0					
* 0202174	6097	20	3W						
* 0202174	7244	1167	7C		1147				
* 0202179	4100	0	3W						
* 0202179	4201	101	3M	101					
* 0202180	5340	23	3W						
* 0202180	5384	67	4D			44			
* 0202180	5657	340	3W						273
* 0202181	7157	230	3W						
* 0202181	7182	255	3W			25			
* 0202181	7630	703	7C		448				
* 0202182	5234	3	4D						
* 0202182	5234	3	7C					0	
* 0202182	5430	196	3W						
* 0202182	6570	1336	3M	1140					
* 0202183	5548	1354	4D						
* 0202183	5624	1430	4D						76
* 0202183	5624	1430	1Z				0		
* 0202188	5484	10	3W						
* 0202188	6122	648	1Z	638					
* 0202189	4678	50	3W						
* 0202189	5280	652	5Q	598					
* 0202189	5280	0	3W						
* 0202189	5436	156	3W			156			
* 0202192	4872	1635	3W						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202192	5056	1819	3W			184			
* 0202192	5059	1822	3W			3			
* 0202192	5137	1900	4D			78			
* 0202192	5169	1932	2N				32		
* 0202192	5218	49	3W						
* 0202192	5860	691	4D			642			
* 0202192	5867	698	1Z				7		
* 0202196	3590	420	3W						
* 0202196	4275	1105	5W	685					
* 0202197	4967	506	3W			3			
* 0202197	5577	1116	3Q	610					
* 0202197	5766	189	4D						
* 0202197	5766	189	3R				0		
* 0202198	5265	37	4D						
* 0202198	5849	621	3W			584			
* 0202198	6062	834	4D			213			
* 0202198	6290	1062	3W						228
* 0202199	5800	753	3W						
* 0202199	6253	1206	7C		453				
* 0202199	6439	186	3W						
* 0202199	7725	1472	7C		1286				
* 0202202	5002	1421	4D						
* 0202202	5036	1455	7C					34	
* 0202202	5197	161	3W						
* 0202202	5566	530	4D			369			
* 0202202	5683	647	7C					117	
* 0202203	3495	47	4D						
* 0202203	3495	47	3W						0
* 0202203	3495	47	5W	0					
* 0202204	5397	137	3W						
* 0202204	5482	222	3W			85			
* 0202204	6388	1128	3W			906			
* 0202204	6388	1128	2Q	0					
* 0202205	4933	914	4D						
* 0202205	4933	914	1Z				0		
* 0202205	4938	5	3W						
* 0202205	5163	230	8F	225					
* 0202206	3923	31	4D						
* 0202206	4390	498	7C					467	
* 0202207	6437	1118	4D						
* 0202207	6793	1474	7C					358	
* 0202208	4624	688	3W						
* 0202208	4624	688	6Q	0					
* 0202208	4624	0	3W						
* 0202208	4649	25	3W			25			
* 0202208	4649	25	3R	0					

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202208	5107	458	4D						
* 0202208	5348	699	8B				241		
* 0202209	4659	138	3W						
* 0202209	5335	814	5G		676				
* 0202210	3581	457	3W						
* 0202210	3592	468	3W			11			
* 0202210	3727	603	4D			135			
* 0202210	3859	735	4D						132
* 0202210	4294	1170	1A				435		
* 0202212	5881	498	3W						
* 0202212	5881	498	3R	0					
* 0202213	5838	317	3W						
* 0202213	5868	347	1A	30					
* 0202214	4983	11	3W						
* 0202214	5431	459	3T	448					
* 0202215	4209	749	3W						
* 0202215	4998	1538	7C		789				
* 0202215	5508	493	4D						
* 0202215	5724	709	7C					216	
* 0202217	4959	0	3W						
* 0202217	5282	323	6J	323					
* 0202218	4107	1278	4D						
* 0202218	4224	1395	7C					117	
* 0202219	4495	426	3W						
* 0202219	4845	776	3W			350			
* 0202219	4854	785	3R	9					
* 0202219	4857	3	4D						
* 0202219	4990	136	4D						133
* 0202219	5426	572	7C					436	
* 0202220	3029	0	3W						
* 0202220	3141	112	3W			112			
* 0202220	3760	731	8F	619					
* 0202222	5709	383	3W			269			
* 0202222	5931	605	3W			222			
* 0202223	7040	414	3W						
* 0202223	7040	414	3A	0					
* 0202224	5150	888	3W						
* 0202224	5164	902	4D			14			
* 0202224	5164	902	1Z				0		
* 0202224	5548	384	3W						
* 0202224	5764	600	3R	216					
* 0202225	5875	2357	3W						
* 0202225	5876	2358	3W			1			
* 0202225	5877	2359	3W			1			
* 0202225	6032	2514	3W			155			
* 0202225	6148	2630	7C		116				

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202226	3455	50	3W						
* 0202226	4554	1149	3T	1099					
* 0202227	5667	200	3W						
* 0202227	5927	460	3W			260			
* 0202227	5927	460	3R	0					
* 0202228	4951	0	3W						
* 0202228	5768	817	6F	817					
* 0202229	4041	170	3W						
* 0202229	4097	226	4D			56			
* 0202229	4097	226	1W				0		
* 0202231	4847	1175	3W						
* 0202231	4851	1179	4D			4			
* 0202231	4851	1179	3A				0		
* 0202231	5366	515	3W						
* 0202231	5378	527	3R	12					
* 0202232	5360	1462	3W						
* 0202232	5412	1514	4D			50			
* 0202232	5412	1514	3A				0		
* 0202234	3815	0	3W						
* 0202234	4121	306	1W	306					
* 0202235	4357	144	4D						
* 0202235	5045	832	2S				688		
* 0202237	4404	0	3W						
* 0202237	4470	66	2S	66					
* 0202237	4785	315	3W						
* 0202237	5241	771	7C		456				
* 0202238	5789	1087	4D						
* 0202238	5845	1143	3W						56
* 0202238	5893	1191	7C		48				
* 0202241	4310	43	4D						
* 0202241	4777	510	4D						467
* 0202241	4777	510	3A				0		
* 0202241	5363	382	3W						
* 0202241	5365	384	3T	2					
* 0202243	4747	981	3W						
* 0202243	4873	1107	4D			126			
* 0202243	5235	1469	4D						362
* 0202243	5235	1469	3W			0			
* 0202243	5277	1511	4D			42			
* 0202244	4705	214	3W						
* 0202244	4892	401	4P	187					
* 0202245	4275	49	3W						
* 0202247	3621	879	3Q	830					
* 0202247	3651	30	3W						
* 0202247	5124	1503	7C		1473				
* 0202248	4330	855	3W						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202248	4340	865	4D			10			
* 0202248	4340	865	1Z				0		
* 0202248	4979	639	3W						
* 0202248	5183	843	7K	204					
* 0202252	3466	579	3W						
* 0202252	3592	705	3W			126			
* 0202252	4323	1436	3W			734			
* 0202252	4334	1447	3R	11					
* 0202253	5297	402	3W						
* 0202253	5298	403	3W			1			
* 0202253	5564	669	3W			266			
* 0202253	5696	801	3W			132			
* 0202254	5900	127	3W						
* 0202254	5922	149	5Q	22					
* 0202254	5992	70	3W						
* 0202254	6670	748	3W			678			
* 0202256	4525	1102	3W						
* 0202256	5042	1619	7C		517				
* 0202256	5163	121	3W						
* 0202256	5258	216	6J	95					
* 0202259	4189	191	3W						
* 0202259	4452	454	4D			263			
* 0202261	4839	250	3W						
* 0202261	5025	436	2S	186					
* 0202261	5432	407	3W						
* 0202261	5484	459	7C		52				
* 0202261	6572	1088	3W						
* 0202261	6696	1212	1W	124					
* 0202262	5036	0	3W						
* 0202262	5036	0	3P	0					
* 0202263	5172	416	3W						
* 0202263	5242	486	7C		70				
* 0202263	6144	372	3W						
* 0202263	6230	458	4D			86			
* 0202263	6348	576	3W						118
* 0202263	6402	630	7C		54				
* 0202264	4124	0	3W						
* 0202264	5226	1102	7C		1102				
* 0202265	4478	623	3W						
* 0202265	4483	628	3W			5			
* 0202265	4522	667	5Q	39					
* 0202267	5742	0	4D						
* 0202267	5753	11	7K				11		
* 0202268	5239	811	3W						
* 0202268	5627	1199	1Z	388					
* 0202269	3596	16	3W						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202269	3602	22	3W			6			
* 0202269	3912	332	5Q	310					
* 0202269	4476	564	3W						
* 0202269	4479	567	3W			3			
* 0202269	4479	567	6Q	0					
* 0202272	4305	410	3W						
* 0202272	4721	826	3W			416			
* 0202272	4826	931	5G		105				
* 0202273	4610	823	4D						
* 0202273	5078	1291	4D						468
* 0202273	5078	1291	3A				0		
* 0202274	2888	731	3W						
* 0202274	3283	1126	3W			395			
* 0202274	3439	1282	4D			156			
* 0202274	3520	1363	7C					81	
* 0202276	4659	181	3W			92			
* 0202276	5359	881	7C		700				
* 0202278	5393	914	3W						
* 0202278	5425	946	2N	32					
* 0202278	5710	225	4D						
* 0202278	6307	822	7C					597	
* 0202278	6373	66	3W						
* 0202278	6554	247	4D			181			
* 0202280	3882	120	3W						
* 0202280	3968	206	6F	86					
* 0202281	4920	1547	3W						
* 0202281	4928	1555	3A	8					
* 0202281	4929	1	4D						
* 0202281	4939	11	8P				10		
* 0202281	5004	65	3W						
* 0202281	5626	687	3W			622			
* 0202281	5954	1015	1Z	328					
* 0202283	3239	91	3W						
* 0202283	3275	127	3W			36			
* 0202283	3718	570	2S	443					
* 0202283	3725	0	3W						
* 0202283	4243	518	3A	518					
* 0202285	4423	271	3W						
* 0202285	5388	1236	3W			965			
* 0202285	5401	1249	3D	13					
* 0202286	2554	686	3W						
* 0202286	2647	779	7C		93				
* 0202287	4405	515	3W						
* 0202287	5538	1648	7C		1133				
* 0202288	4124	847	3W						
* 0202288	4211	934	3T	87					

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202290	4369	155	3W						
* 0202290	4585	371	3Q	216					
* 0202290	4782	197	3W						
* 0202290	4812	227	5Q	30					
* 0202290	4889	77	3W						
* 0202290	5430	618	5Q	541					
* 0202291	4002	672	3W						
* 0202291	4146	816	3R	144					
* 0202291	4232	83	3W						
* 0202291	5302	1153	4D			1070			
* 0202291	5302	1153	1W				0		
* 0202293	4420	224	3W						
* 0202293	4634	438	1Z	214					
* 0202293	4634	0	3W						
* 0202293	4668	34	3W			34			
* 0202293	4760	126	3W			92			
* 0202293	4782	148	4D			22			
* 0202293	4788	154	1Z				6		
* 0202294	4376	513	3W						
* 0202294	4750	887	6N	374					
* 0202297	4698	927	4D						
* 0202297	4698	927	5G					0	
* 0202298	3903	197	3W						
* 0202298	4166	460	3W			263			
* 0202298	4172	466	3W			6			
* 0202298	4227	521	3M	55					
* 0202299	6134	339	3W						
* 0202299	6862	1067	7C		728				
* 0202300	3799	705	3W						
* 0202300	3956	862	1Z	157					
* 0202304	3285	271	3W						
* 0202304	3304	290	1Z	19					
* 0202304	3436	132	4D						
* 0202304	3551	247	7C					115	
* 0202306	3756	373	3W						
* 0202306	3911	528	3W			155			
* 0202306	3921	538	3W			10			
* 0202306	3921	538	3D	0					
* 0202306	4227	306	3W						
* 0202306	4345	424	3W			118			
* 0202306	4377	456	1Z	32					
* 0202307	4486	3	3W						
* 0202307	4593	110	3W			107			
* 0202307	4686	203	7C		93				
* 0202308	4450	181	4D						
* 0202308	4541	272	1Z				91		

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202309	4347	574	3W						
* 0202309	4760	987	7C		413				
* 0202310	4249	1205	3W						
* 0202310	4249	1205	3W			0			
* 0202310	4501	1457	4D						252
* 0202310	4649	1605	4D						148
* 0202311	4117	365	3W						
* 0202311	4117	365	3W			0			
* 0202311	4370	618	4D			253			
* 0202312	3803	338	3W						
* 0202312	4022	557	2N	219					
* 0202313	3100	139	3W						
* 0202313	3252	291	3W			152			
* 0202313	3634	673	4D			382			
* 0202313	4347	1386	7C					713	
* 0202313	5650	547	3W						
* 0202313	5759	656	7C		109				
* 0202314	2674	198	3W						
* 0202314	2910	434	3W			236			
* 0202314	3112	636	4D			202			
* 0202314	3849	1373	3W						737
* 0202317	3723	518	4D						
* 0202317	3723	518	3W						0
* 0202317	3800	595	7C		77				
* 0202317	3808	8	3W						
* 0202317	4173	373	8B	365					
* 0202319	4814	112	3W						
* 0202319	4970	268	1Z	156					
* 0202321	4445	0	4D						
* 0202321	4974	529	7K				529		
* 0202322	4028	117	4D						
* 0202322	4100	189	5Q				72		
* 0202322	4141	41	3W						
* 0202322	5098	998	1Z	957					
* 0202323	4442	196	3W						
* 0202323	4638	392	8P	196					
* 0202323	4762	124	4D						
* 0202323	5750	1112	7C					988	
* 0202324	4443	457	3W						
* 0202324	4750	764	3W			307			
* 0202326	4399	444	3W						
* 0202326	4403	448	3A	4					
* 0202327	4909	297	3W						
* 0202327	6096	1484	7C		1187				
* 0202327	6318	222	3W						
* 0202327	6538	442	3W			220			

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202327	6609	513	4R	71					
* 0202329	5777	687	3W						
* 0202329	5971	881	7C		194				
* 0202333	4781	339	3W						
* 0202333	4966	524	8B	185					
* 0202334	5165	1178	3W						
* 0202334	5431	1444	7C		266				
* 0202334	5431	0	3W						
* 0202334	5644	213	2N	213					
* 0202335	5369	1298	4D						
* 0202335	5609	1538	7C					240	
* 0202336	5380	225	4D						
* 0202336	5380	225	3A				0		
* 0202336	5380	0	3W						
* 0202338	3678	716	7C		716				
* 0202340	5195	335	3W						
* 0202340	5413	553	7C		218				
* 0202341	5337	845	3W						
* 0202341	5612	1120	4D			275			
* 0202341	5777	1285	4D						165
* 0202344	5154	663	3W						
* 0202344	5253	762	5G		99				
* 0202348	4513	54	3W						
* 0202348	4555	96	7K	42					
* 0202348	4640	85	3W						
* 0202348	5945	1390	3W			1305			
* 0202348	5945	1390	3R	0					
* 0202350	4914	300	3W						
* 0202350	6161	1547	3W			1247			
* 0202353	5210	731	3W						
* 0202353	5541	1062	3Q	331					
* 0202354	4880	1447	3W						
* 0202354	4883	1450	4D			3			
* 0202354	4883	1450	1Z				0		
* 0202354	5027	144	3W						
* 0202354	5165	282	3W			138			
* 0202354	5488	605	8F	323					
* 0202354	5522	34	3W						
* 0202354	6593	1105	7C		1071				
* 0202355	4322	1298	4D						
* 0202355	4490	1466	7C					168	
* 0202355	4775	284	3W						
* 0202355	5506	1015	3W			731			
* 0202355	5522	1031	7K	16					
* 0202355	5539	17	4D						
* 0202355	5904	382	1Z				365		

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202356	4791	133	3W						
* 0202356	4973	315	4D			182			
* 0202356	4973	315	1Z				0		
* 0202356	5409	436	3W						
* 0202356	5772	799	3T	363					
* 0202357	2146	31	3W						
* 0202357	2673	558	7C		527				
* 0202357	3701	750	3W						
* 0202358	4897	752	7C		2				
* 0202358	5207	310	3W						
* 0202358	5207	310	8P	0					
* 0202359	5094	346	3W						
* 0202359	6137	1389	7C		1043				
* 0202360	3304	145	3W						
* 0202360	3352	193	3W			48			
* 0202360	3352	193	1G	0					
* 0202360	3546	0	3W						
* 0202360	4101	555	3R	555					
* 0202361	4074	779	3W						
* 0202361	4347	1052	3W			273			
* 0202361	4356	1061	4D			9			
* 0202361	4365	1070	7C					9	
* 0202362	4323	566	3W						
* 0202362	4576	819	3Q	253					
* 0202363	4005	4	3W						
* 0202363	4053	52	3W			48			
* 0202363	4145	144	3W			92			
* 0202363	4280	279	7K	135					
* 0202363	5016	266	3W						
* 0202363	5024	274	5Q	8					
* 0202366	4648	220	3W						
* 0202366	4904	476	3W			256			
* 0202366	4968	540	5Q	64					
* 0202368	4080	390	3W						
* 0202368	4447	757	1W	367					
* 0202368	4894	447	3W						
* 0202368	4970	523	4D			76			
* 0202368	5225	778	7C					255	
* 0202369	4631	367	3W						
* 0202369	4700	436	3W			69			
* 0202369	5015	751	7C		315				
* 0202370	5656	288	4D						
* 0202370	5884	516	7C					228	
* 0202373	5046	71	4D						
* 0202373	5046	71	3R				0		
* 0202374	2820	0	3W						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202374	3838	1018	5Q	1018					
* 0202375	5946	579	4D						
* 0202375	5946	579	3T				0		
* 0202377	3519	427	3W						
* 0202377	3701	609	3Q	182					
* 0202377	3714	13	3W						
* 0202377	4178	477	3P	464					
* 0202378	4138	0	3W						
* 0202378	5079	941	3Q	941					
* 0202378	5917	838	3W						
* 0202378	6199	1120	7C		282				
* 0202379	3410	1223	3W						
* 0202379	3804	1617	2C	394					
* 0202379	4403	294	3W						
* 0202379	4584	475	7C		181				
* 0202380	4746	30	3W						
* 0202380	5144	428	8P	398					
* 0202381	2836	52	3W						
* 0202381	2970	186	7D		134				
* 0202381	2978	8	4D						
* 0202381	3855	885	7C					878	
* 0202384	4146	734	3W						
* 0202384	4406	994	3W			260			
* 0202384	4428	1016	3W			22			
* 0202384	4479	1067	3W			51			
* 0202384	4630	1218	2N	151					
* 0202385	4196	142	4D						
* 0202385	4840	786	7K				644		
* 0202386	4551	12	3W						
* 0202386	4711	172	3W			160			
* 0202386	5093	554	3W			382			
* 0202386	5726	1187	3B	633					
* 0202388	3562	76	3W						
* 0202388	3845	359	4D			283			
* 0202388	3851	365	3W			6			
* 0202388	3855	369	4D			4			
* 0202388	4186	700	7D					331	
* 0202390	5473	648	3W						
* 0202390	5578	753	3W			105			
* 0202390	5679	854	7C		101				
* 0202391	3328	170	3W						
* 0202391	3575	417	4P	247					
* 0202392	2619	55	4D						
* 0202392	2619	55	3R				0		
* 0202394	2317	673	3W						
* 0202394	2496	852	7C		179				

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202394	3768	207	3W						
* 0202394	3800	239	1Z	32					
* 0202395	4837	778	3W						
* 0202395	4954	895	4D			117			
* 0202395	5291	1232	7C					337	
* 0202397	3118	972	3W						
* 0202397	3119	973	3W			1			
* 0202397	3119	973	3R	0					
* 0202398	4618	1496	3W						
* 0202398	4720	1598	3R	102					
* 0202398	4963	243	3W						
* 0202398	5132	412	3W			169			
* 0202398	5212	492	4D			80			
* 0202398	5212	492	3R				0		
* 0202400	4288	130	4D						
* 0202400	4463	305	7C					175	
* 0202401	4199	32	3W						
* 0202401	4577	410	4D			378			
* 0202401	4777	610	7C					200	
* 0202401	5842	987	3W						
* 0202401	5842	987	7C		0				
* 0202402	5019	2120	3W						
* 0202402	5027	2128	1Z	8					
* 0202402	5047	20	3W						
* 0202402	5047	20	3W			0			
* 0202402	5474	447	8F	227					
* 0202403	4777	478	3W						
* 0202403	5027	728	3R	250					
* 0202404	4700	145	3W						
* 0202404	5064	509	5B	364					
* 0202405	3549	110	3W						
* 0202405	3679	240	2N	130					
* 0202406	3358	553	3W						
* 0202406	3635	830	1Z	277					
* 0202409	5098	0	3W						
* 0202409	5845	747	7L	747					
* 0202410	4266	979	3W						
* 0202410	4454	1167	3W			188			
* 0202410	4463	1176	3A	9					
* 0202410	5750	111	4D						
* 0202410	5765	126	3W						15
* 0202412	4554	1551	3W						
* 0202412	4576	1573	3W			22			
* 0202412	4594	1591	3W			18			
* 0202412	4603	1600	3W			9			
* 0202412	4606	1603	3W			3			

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202412	4616	1613	4D			10			
* 0202412	4616	1613	3A				0		
* 0202412	4753	137	3W						
* 0202412	5144	528	3W			391			
* 0202412	5773	1157	3W			629			
* 0202413	4939	431	3W						
* 0202413	5031	523	1Z	92					
* 0202416	3059	226	4D			226			
* 0202416	3534	701	3W						475
* 0202416	4010	1177	3W			476			
* 0202416	4113	1280	3W			103			
* 0202416	4476	1643	7D		363				
* 0202416	4692	216	3W						
* 0202416	4863	387	6J	171					
* 0202417	4837	31	3W						
* 0202417	5052	246	3W			215			
* 0202417	6405	1599	7C		1353				
* 0202419	2194	273	4D						
* 0202419	2413	492	6N				219		
* 0202420	4459	54	3W						
* 0202420	4799	394	4D			340			
* 0202420	4899	494	6F				100		
* 0202420	4903	4	4D						
* 0202420	5204	305	3W						301
* 0202420	5830	931	7C		626				
* 0202421	3971	525	3W						
* 0202421	3974	528	4D			3			
* 0202421	4244	798	5Q				270		
* 0202423	4079	1246	3W						
* 0202423	4190	1357	3W			111			
* 0202423	4200	1367	3W			10			
* 0202424	4003	520	3W						
* 0202424	4268	785	8C	265					
* 0202424	4417	149	4D						
* 0202424	4511	243	1W				94		
* 0202426	5523	47	4D						
* 0202426	5523	47	3A				0		
* 0202428	3009	52	3W						
* 0202428	3059	102	3W			50			
* 0202428	3119	162	3Q	60					
* 0202428	3408	289	3W						
* 0202428	3635	516	4D			227			
* 0202428	3635	516	6Q				0		
* 0202433	3892	1157	4D						
* 0202433	3892	1157	3A				0		
* 0202434	3357	141	4D						

APPENDIX C. CANNIBALIZATION AND DIRECTED REMOVAL DATA

Serial Number	Flight Hours Since New	Flight Hours Since Repair	Reason for Removal	3W followed by Failure	3W followed by 5G,7C,7D	3W followed by 3W or 4D	4D followed by Failure	4D followed by 5G,7C,7D	4D followed by 3W or 4D
* 0202434	3527	311	4D						170
* 0202434	3612	396	3W						85
* 0202434	3693	477	7C		81				
* 0202438	4406	407	3W						
* 0202438	5315	1316	3W			909			
* 0202438	5418	1419	5W	103					
* 0202438	5574	156	3W						
* 0202439	4403	811	3Q	655					
* 0202439	4552	149	4D						
* 0202439	4552	149	1Z				0		
* 0202440	5149	0	3W						
* 0202440	5871	722	3W			722			
* 0202440	5892	743	7C		21				
* 0202441	5383	584	3W						
* 0202441	5387	588	4D			4			
* 0202441	5387	588	5G				0		
* 0202441	5938	551	3W						
* 0202441	5946	559	1Z	8					
* 0202443	4455	470	3W						
* 0202443	5347	1362	3A	892					
* 0202444	4619	846	4D						
* 0202444	4619	846	7D					0	
* 0202444	4656	0	3W						
* 0202444	4660	4	1Z	4					

APPENDIX D. SPREADSHEET PROCEDURES

A. NON-PARAMETRIC STEP-BY-STEP SPREADSHEET PROCEDURES

The following step-by-step procedures were used to setup the spreadsheet for calculations of the Non-parametric statistical functions and all cell locations refer to Table 13. The failure times used for calculation included all failure times, as used in Table 2, and will be used as an example throughout the procedure. Table 13 was expanded to show the formula's that were used in each cell location. The failure times data was compressed to fit the table to two pages. The cell locations used for the failure times would be applicable if the full data was shown. The spreadsheet formula's represent equations 3 through 5.

Step 1: Setup the spreadsheet in accordance with Table 13.

Step 2: Enter the failure data in column B in ascending order. The data used for this thesis is listed in Appendix A and includes 723 records. In column A number the failure times in sequential order, this is assigning an index number for use in the calculations. The index numbers for the full set of data is in Appendix B.

Step 3: The total of all failure hours is calculated in cell B725, using the sum function of the spreadsheet.

Step 4: MTBF, Standard Deviation, and Median are calculated in cells F45, F46, and F47 respectfully, by using those function capabilities of the spreadsheet.

Step 5: The failure hours in cells D4..43 can be set to any interval and length. The length used was based on the maximum time for a high time component removal. Using the failure times in column B, find the index record for the failure time that is just below the time listed in cells D4..43 (i.e. in Appendix B the failure time closest to 50 but does not exceed 50 is 48 and this has an index of 124) and put this index number in cells E4..E43, for each corresponding time.

Step 6: F(t), the CDF is calculated using equation 3 in cells G4..43.

Step 7: R(t), Reliability is calculated using equation 4 in cells H4..43.

Step 8: Conditional Reliability is calculated using equation 5. The times used for this were 300 to 1500 hours, for demonstration purposes on 300, 1400 and 1500 were used. See Table 3 for a full set of values.

	A	B	C	D	E	F	G	H
1	Index	Fail Times		Failure	Index	Reliability	CDF	
2	1	0		Hrs	Number			
3	2	0		t	i(t)	R(t)	F(t)	
4	3	0		**50**	124	=1-G4	=+E4/723	
5	4	0		**100**	172	=1-G5	=+E5/723	
6	5	0		**150**	197	=1-G6	=+E6/723	
7	6	0		**200**	229	=1-G7	=+E7/723	
8	7	0		**250**	275	=1-G8	=+E8/723	
9	8	0		**300**	305	=1-G9	=+E9/723	
10	9	0		**350**	340	=1-G10	=+E10/723	
11	10	0		**400**	376	=1-G11	=+E11/723	
12	11	0		**450**	407	=1-G12	=+E12/723	
13	12	0		**500**	440	=1-G13	=+E13/723	
14	13	0		**550**	462	=1-G14	=+E14/723	
15	14	0		**600**	487	=1-G15	=+E15/723	
16	15	0		**650**	503	=1-G16	=+E16/723	
17	16	0		**700**	526	=1-G17	=+E17/723	
18	17	0		**750**	541	=1-G18	=+E18/723	
19	18	0		**800**	555	=1-G19	=+E19/723	
20	19	0		**850**	571	=1-G20	=+E20/723	
21	20	0		**900**	590	=1-G21	=+E21/723	
22	21	0		**950**	605	=1-G22	=+E22/723	
23	22	0		**1000**	620	=1-G23	=+E23/723	
24	23	0		**1050**	633	=1-G24	=+E24/723	
25	24	0		**1100**	644	=1-G25	=+E25/723	
26	25	0		**1150**	657	=1-G26	=+E26/723	
27	26	0		**1200**	673	=1-G27	=+E27/723	
28	27	0		**1250**	679	=1-G28	=+E28/723	
29	28	0		**1300**	685	=1-G29	=+E29/723	
30	29	0		**1350**	689	=1-G30	=+E30/723	
31	30	0		**1400**	701	=1-G31	=+E31/723	
32	31	0		**1450**	708	=1-G32	=+E32/723	
33	32	0		**1500**	714	=1-G33	=+E33/723	
34	33	0		**1550**	716	=1-G34	=+E34/723	
35	34	0		**1600**	718	=1-G35	=+E35/723	
36	35	0		**1650**	721	=1-G36	=+E36/723	
37	36	0		**1700**	721	=1-G37	=+E37/723	
38	37	0		**1750**	721	=1-G38	=+E38/723	
39	38	0		**1800**	721	=1-G39	=+E39/723	
40	39	0		**1850**	721	=1-G40	=+E40/723	
41	40	1		**1900**	721	=1-G41	=+E41/723	
42	41	1		**1950**	722	=1-G42	=+E42/723	
43				**2000**	722	=1-G43	=+E43/723	
44	719	1613						
45	720	1617				**MTBF**	=AVERAGE(B2:B725)	
46	721	1638				**Std Dev**	=STDEV(B2:B725)	
47	722	1932				**Median**	= MEDIAN(B2:B725)	
48	723	2128						
49								
50	**Total Hrs**	=SUM(B2:B725)						

Table 13. Formulas used in Nonparametric calculations (All failure times)

	I	J	K	L	M
1	Failure	Index	300 Hrs	1400 Hrs	1500 Hrs
2	Hrs	Number	Prob	Prob	Prob
3					
4	50	124	=(723-$B$9)/(723-$B4)	=(723-$B$31)/(723-$B4)	=(723-$B$33)/(723-$B4)
5	100	172	=(723-$B$9)/(723-$B5)	=(723-$B$31)/(723-$B5)	=(723-$B$33)/(723-$B5)
6	150	197	=(723-$B$9)/(723-$B6)	=(723-$B$31)/(723-$B6)	=(723-$B$33)/(723-$B6)
7	200	229	=(723-$B$9)/(723-$B7)	=(723-$B$31)/(723-$B7)	=(723-$B$33)/(723-$B7)
8	250	275	=(723-$B$9)/(723-$B8)	=(723-$B$31)/(723-$B8)	=(723-$B$33)/(723-$B8)
9	300	305	=(723-$B$9)/(723-$B9)	=(723-$B$31)/(723-$B9)	=(723-$B$33)/(723-$B9)
10	350	340		=(723-$B$31)/(723-$B10)	=(723-$B$33)/(723-$B10)
11	400	376		=(723-$B$31)/(723-$B11)	=(723-$B$33)/(723-$B11)
12	450	407		=(723-$B$31)/(723-$B12)	=(723-$B$33)/(723-$B12)
13	500	440		=(723-$B$31)/(723-$B13)	=(723-$B$33)/(723-$B13)
14	550	462		=(723-$B$31)/(723-$B14)	=(723-$B$33)/(723-$B14)
15	600	487		=(723-$B$31)/(723-$B15)	=(723-$B$33)/(723-$B15)
16	650	503		=(723-$B$31)/(723-$B16)	=(723-$B$33)/(723-$B16)
17	700	526		=(723-$B$31)/(723-$B17)	=(723-$B$33)/(723-$B17)
18	750	541		=(723-$B$31)/(723-$B18)	=(723-$B$33)/(723-$B18)
19	800	555		=(723-$B$31)/(723-$B19)	=(723-$B$33)/(723-$B19)
20	850	571		=(723-$B$31)/(723-$B20)	=(723-$B$33)/(723-$B20)
21	900	590		=(723-$B$31)/(723-$B21)	=(723-$B$33)/(723-$B21)
22	950	605		=(723-$B$31)/(723-$B22)	=(723-$B$33)/(723-$B22)
23	1000	620		=(723-$B$31)/(723-$B23)	=(723-$B$33)/(723-$B23)
24	1050	633		=(723-$B$31)/(723-$B24)	=(723-$B$33)/(723-$B24)
25	1100	644		=(723-$B$31)/(723-$B25)	=(723-$B$33)/(723-$B25)
26	1150	657		=(723-$B$31)/(723-$B26)	=(723-$B$33)/(723-$B26)
27	1200	673		=(723-$B$31)/(723-$B27)	=(723-$B$33)/(723-$B27)
28	1250	679		=(723-$B$31)/(723-$B28)	=(723-$B$33)/(723-$B28)
29	1300	685		=(723-$B$31)/(723-$B29)	=(723-$B$33)/(723-$B29)
30	1350	689		=(723-$B$31)/(723-$B30)	=(723-$B$33)/(723-$B30)
31	1400	701		=(723-$B$31)/(723-$B31)	=(723-$B$33)/(723-$B31)
32	1450	708			=(723-$B$33)/(723-$B32)
33	1500	714			=(723-$B$33)/(723-$B33)
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					

Table 13. Formulas used in Nonparametric calculations (All failure times)

B. WEIBULL DISTRIBUTION STEP-BY-STEP SPREADSHEET PROCEDURES

The following step-by-step procedures were used to setup the spreadsheet for calculations of the Weibull distribution statistical functions and all cell locations refer to Table 14. The failure times used for included all failure times, as used in Table 6, and will be used as an example throughout the procedure. Table 14 was expanded to show the formula's that were used in each cell location. The failure times data was compressed to fit the table to three pages. The cell locations used for the failure times would be applicable if the full data was shown. The spreadsheet formulas represent equations 17 through 22, and 24 through 26.

Step 1: Setup the spreadsheet in accordance with Table 14.

Step 2: Enter the failure data in column A in ascending order. The data used for this thesis is listed in Appendix A and included 723 records. Enter the total number of records in cell H46.

Step 3: To start the calculations a value of 1.0000 was initially used for β.

Step 4: Column B is the failure time raised to the β power and Column C is the failure time raised to the 2β power. The symbol (^) is used to raise a number to some factor.

Step 5: β is determined through an itteration process of trial and error. Excel has an excellent tool, "Goal Seek", that performs this function in a matter of seconds. In cell location H47, equation 24 was rearranged so the number of records was set to equal the rest of the formula. Since the number of failure times is known, then using "Goal Seek" from the TOOLS menu, cell H47 be solved for the value in cell H46 (723) by varying the value of cell H48.

Step 6: θ is calculated using equation 25 in cell H49.

Step 7: MTBF is calculated using equation 21 in cell H50.

Step 8: Variance is calculated using equation 22 in cell H51. The values for cell K47 ($1 + 1/\beta$) and cell K48 ($1 + 2/\beta$) are first calculated and then by using Table 15, the number calculated is converted to a Gamma function number in cells L47 and L48, respectfully. If the value in cells K47 or K48 exceeds 2, then one must be subtracted first and then the gamma value found for the new number and multiply it times the value left over after subtracting one. For example, in Table 6 the value for all failures of $1 + 2/\beta$ was 2.650. Therefore, 2.650 - 1 = 1.650, then it becomes $1.650[\Gamma(1.650)]$, which is 1.650*(0.90012), which equals 1.48520, as shown in Table 6.

Step 9: Standard Deviation is calculated in cell H52 by taking the square root of the variance.

Step 10: Using the function capabilities of the spreadsheet, the Weibull PDF (cells H:5..44) and CDF (cells I:5..44) can be computed using the β and θ values that were calculated in cells H48 and H49.

Step 11: Failure rate can be calculated using equation 19 in cells J:5..44.

Step 12: Reliability can be calculated using equation 18 in cells K:5..44.

Step 13: Conditional Probability is calculated using equation 26. The times used for this were 300 to 1500 hours, for demonstration purposes on 300, 1400 and 1500 were used. See Table 7 for a full set of values.

	A	B	C	D	E	F	G
1	Fail Times	T^B	T^2B				
2	0	=+A2^I48	=+A2^(2*I48)				
3	0	=+A3^I48	=+A3^(2*I48)				
4	0	=+A4^I48	=+A4^(2*I48)				
5	0	=+A5^I48	=+A5^(2*I48)				
6	0	=+A6^I48	=+A6^(2*I48)				
7	0	=+A7^I48	=+A7^(2*I48)				
8	0	=+A8^I48	=+A8^(2*I48)				
9	0	=+A9^I48	=+A9^(2*I48)				
10	0	=+A10^I48	=+A10^(2*I48)				
11	0	=+A11^I48	=+A11^(2*I48)				
12	0	=+A12^I48	=+A12^(2*I48)				
13	0	=+A13^I48	=+A13^(2*I48)				
14	0	=+A14^I48	=+A14^(2*I48)				
15	0	=+A15^I48	=+A15^(2*I48)				
16	0	=+A16^I48	=+A16^(2*I48)				
17	0	=+A17^I48	=+A17^(2*I48)				
18	0	=+A18^I48	=+A18^(2*I48)				
19	0	=+A19^I48	=+A19^(2*I48)				
20	0	=+A20^I48	=+A20^(2*I48)				
21	0	=+A21^I48	=+A21^(2*I48)				
22	0	=+A22^I48	=+A22^(2*I48)				
23	0	=+A23^I48	=+A23^(2*I48)				
24	0	=+A24^I48	=+A24^(2*I48)				
25	0	=+A25^I48	=+A25^(2*I48)				
26	0	=+A26^I48	=+A26^(2*I48)				
27	0	=+A27^I48	=+A27^(2*I48)				
28	0	=+A28^I48	=+A28^(2*I48)				
29	0	=+A29^I48	=+A29^(2*I48)				
30	0	=+A30^I48	=+A30^(2*I48)				
31	0	=+A31^I48	=+A31^(2*I48)				
32	0	=+A32^I48	=+A32^(2*I48)				
33	0	=+A33^I48	=+A33^(2*I48)				
34	0	=+A34^I48	=+A34^(2*I48)				
35	0	=+A35^I48	=+A35^(2*I48)				
36	0	=+A36^I48	=+A36^(2*I48)				
37	0	=+A37^I48	=+A37^(2*I48)				
38	0	=+A38^I48	=+A38^(2*I48)				
39	0	=+A39^I48	=+A39^(2*I48)				
40	0	=+A40^I48	=+A40^(2*I48)				
41	1	=+A41^I48	=+A41^(2*I48)				
42	1	=+A42^I48	=+A42^(2*I48)				
43	1	=+A43^I48	=+A43^(2*I48)				
44							
45	1613	=+A720^I48	=+A720^(2*I48)				
46	1617	=+A721^I48	=+A721^(2*I48)				
47	1638	=+A722^I48	=+A722^(2*I48)				
48	1932	=+A723^I48	=+A723^(2*I48)				
49	2128	=+A724^I48	=+A724^(2*I48)				
50							
51	=SUM(A2:A726)	=SUM(B2:B726)	=SUM(C2:C726)				
52							
53							
54							
55							

Table 14. Formulas used in Weibull calculations (All failure times)

	H	I	J
1	Failure	Weibull	Weibull
2	Times	PDF	CDF
3	t	f(t)	F(t)
4			
5	50	=WEIBULL(H5,$I$48,$I$49,FALSE)	=WEIBULL(H5,$I$48,$I$49,TRUE)
6	100	=WEIBULL(H6,$I$48,$I$49,FALSE)	=WEIBULL(H6,$I$48,$I$49,TRUE)
7	150	=WEIBULL(H7,$I$48,$I$49,FALSE)	=WEIBULL(H7,$I$48,$I$49,TRUE)
8	200	=WEIBULL(H8,$I$48,$I$49,FALSE)	=WEIBULL(H8,$I$48,$I$49,TRUE)
9	250	=WEIBULL(H9,$I$48,$I$49,FALSE)	=WEIBULL(H9,$I$48,$I$49,TRUE)
10	300	=WEIBULL(H10,$I$48,$I$49,FALSE)	=WEIBULL(H10,$I$48,$I$49,TRUE)
11	350	=WEIBULL(H11,$I$48,$I$49,FALSE)	=WEIBULL(H11,$I$48,$I$49,TRUE)
12	400	=WEIBULL(H12,$I$48,$I$49,FALSE)	=WEIBULL(H12,$I$48,$I$49,TRUE)
13	450	=WEIBULL(H13,$I$48,$I$49,FALSE)	=WEIBULL(H13,$I$48,$I$49,TRUE)
14	500	=WEIBULL(H14,$I$48,$I$49,FALSE)	=WEIBULL(H14,$I$48,$I$49,TRUE)
15	550	=WEIBULL(H15,$I$48,$I$49,FALSE)	=WEIBULL(H15,$I$48,$I$49,TRUE)
16	600	=WEIBULL(H16,$I$48,$I$49,FALSE)	=WEIBULL(H16,$I$48,$I$49,TRUE)
17	650	=WEIBULL(H17,$I$48,$I$49,FALSE)	=WEIBULL(H17,$I$48,$I$49,TRUE)
18	700	=WEIBULL(H18,$I$48,$I$49,FALSE)	=WEIBULL(H18,$I$48,$I$49,TRUE)
19	750	=WEIBULL(H19,$I$48,$I$49,FALSE)	=WEIBULL(H19,$I$48,$I$49,TRUE)
20	800	=WEIBULL(H20,$I$48,$I$49,FALSE)	=WEIBULL(H20,$I$48,$I$49,TRUE)
21	850	=WEIBULL(H21,$I$48,$I$49,FALSE)	=WEIBULL(H21,$I$48,$I$49,TRUE)
22	900	=WEIBULL(H22,$I$48,$I$49,FALSE)	=WEIBULL(H22,$I$48,$I$49,TRUE)
23	950	=WEIBULL(H23,$I$48,$I$49,FALSE)	=WEIBULL(H23,$I$48,$I$49,TRUE)
24	1000	=WEIBULL(H24,$I$48,$I$49,FALSE)	=WEIBULL(H24,$I$48,$I$49,TRUE)
25	1050	=WEIBULL(H25,$I$48,$I$49,FALSE)	=WEIBULL(H25,$I$48,$I$49,TRUE)
26	1100	=WEIBULL(H26,$I$48,$I$49,FALSE)	=WEIBULL(H26,$I$48,$I$49,TRUE)
27	1150	=WEIBULL(H27,$I$48,$I$49,FALSE)	=WEIBULL(H27,$I$48,$I$49,TRUE)
28	1200	=WEIBULL(H28,$I$48,$I$49,FALSE)	=WEIBULL(H28,$I$48,$I$49,TRUE)
29	1250	=WEIBULL(H29,$I$48,$I$49,FALSE)	=WEIBULL(H29,$I$48,$I$49,TRUE)
30	1300	=WEIBULL(H30,$I$48,$I$49,FALSE)	=WEIBULL(H30,$I$48,$I$49,TRUE)
31	1350	=WEIBULL(H31,$I$48,$I$49,FALSE)	=WEIBULL(H31,$I$48,$I$49,TRUE)
32	1400	=WEIBULL(H32,$I$48,$I$49,FALSE)	=WEIBULL(H32,$I$48,$I$49,TRUE)
33	1450	=WEIBULL(H33,$I$48,$I$49,FALSE)	=WEIBULL(H33,$I$48,$I$49,TRUE)
34	1500	=WEIBULL(H34,$I$48,$I$49,FALSE)	=WEIBULL(H34,$I$48,$I$49,TRUE)
35	1550	=WEIBULL(H35,$I$48,$I$49,FALSE)	=WEIBULL(H35,$I$48,$I$49,TRUE)
36	1600	=WEIBULL(H36,$I$48,$I$49,FALSE)	=WEIBULL(H36,$I$48,$I$49,TRUE)
37	1650	=WEIBULL(H37,$I$48,$I$49,FALSE)	=WEIBULL(H37,$I$48,$I$49,TRUE)
38	1700	=WEIBULL(H38,$I$48,$I$49,FALSE)	=WEIBULL(H38,$I$48,$I$49,TRUE)
39	1750	=WEIBULL(H39,$I$48,$I$49,FALSE)	=WEIBULL(H39,$I$48,$I$49,TRUE)
40	1800	=WEIBULL(H40,$I$48,$I$49,FALSE)	=WEIBULL(H40,$I$48,$I$49,TRUE)
41	1850	=WEIBULL(H41,$I$48,$I$49,FALSE)	=WEIBULL(H41,$I$48,$I$49,TRUE)
42	1900	=WEIBULL(H42,$I$48,$I$49,FALSE)	=WEIBULL(H42,$I$48,$I$49,TRUE)
43	1950	=WEIBULL(H43,$I$48,$I$49,FALSE)	=WEIBULL(H43,$I$48,$I$49,TRUE)
44	2000	=WEIBULL(H44,$I$48,$I$49,FALSE)	=WEIBULL(H44,$I$48,$I$49,TRUE)
45			
46	RECORDS	723	
47	TRIAL	=+B726/((1/(I46-1)*(C726-(B726^2/I46)))^0.5)	
48	BETA	1.2121024440109	
49	THETA	=(+B726/I46)^(1/I48)	
50	MTBF	=+I49*#REF!	
51	VARIANCE	=(+I49^2)*(#REF!-(#REF!^2))	
52	STD DEV	=SQRT(I51)	
53			
54			
55			

Table 14. Formulas used in Weibull calculations (All failure times)

	K	L	M	N
1	Failure	Reliability		
2	Rate			
3	h(t)	R(t)		
4				
5	=(+$I$48/($I$49^$I$48))*((H5)^($I$48-1))	=EXP(-((H5/$I$49)^$I$48))		
6	=(+$I$48/($I$49^$I$48))*((H6)^($I$48-1))	=EXP(-((H6/$I$49)^$I$48))		
7	=(+$I$48/($I$49^$I$48))*((H7)^($I$48-1))	=EXP(-((H7/$I$49)^$I$48))		
8	=(+$I$48/($I$49^$I$48))*((H8)^($I$48-1))	=EXP(-((H8/$I$49)^$I$48))		
9	=(+$I$48/($I$49^$I$48))*((H9)^($I$48-1))	=EXP(-((H9/$I$49)^$I$48))		
10	=(+$I$48/($I$49^$I$48))*((H10)^($I$48-1))	=EXP(-((H10/$I$49)^$I$48))		
11	=(+$I$48/($I$49^$I$48))*((H11)^($I$48-1))	=EXP(-((H11/$I$49)^$I$48))		
12	=(+$I$48/($I$49^$I$48))*((H12)^($I$48-1))	=EXP(-((H12/$I$49)^$I$48))		
13	=(+$I$48/($I$49^$I$48))*((H13)^($I$48-1))	=EXP(-((H13/$I$49)^$I$48))		
14	=(+$I$48/($I$49^$I$48))*((H14)^($I$48-1))	=EXP(-((H14/$I$49)^$I$48))		
15	=(+$I$48/($I$49^$I$48))*((H15)^($I$48-1))	=EXP(-((H15/$I$49)^$I$48))		
16	=(+$I$48/($I$49^$I$48))*((H16)^($I$48-1))	=EXP(-((H16/$I$49)^$I$48))		
17	=(+$I$48/($I$49^$I$48))*((H17)^($I$48-1))	=EXP(-((H17/$I$49)^$I$48))		
18	=(+$I$48/($I$49^$I$48))*((H18)^($I$48-1))	=EXP(-((H18/$I$49)^$I$48))		
19	=(+$I$48/($I$49^$I$48))*((H19)^($I$48-1))	=EXP(-((H19/$I$49)^$I$48))		
20	=(+$I$48/($I$49^$I$48))*((H20)^($I$48-1))	=EXP(-((H20/$I$49)^$I$48))		
21	=(+$I$48/($I$49^$I$48))*((H21)^($I$48-1))	=EXP(-((H21/$I$49)^$I$48))		
22	=(+$I$48/($I$49^$I$48))*((H22)^($I$48-1))	=EXP(-((H22/$I$49)^$I$48))		
23	=(+$I$48/($I$49^$I$48))*((H23)^($I$48-1))	=EXP(-((H23/$I$49)^$I$48))		
24	=(+$I$48/($I$49^$I$48))*((H24)^($I$48-1))	=EXP(-((H24/$I$49)^$I$48))		
25	=(+$I$48/($I$49^$I$48))*((H25)^($I$48-1))	=EXP(-((H25/$I$49)^$I$48))		
26	=(+$I$48/($I$49^$I$48))*((H26)^($I$48-1))	=EXP(-((H26/$I$49)^$I$48))		
27	=(+$I$48/($I$49^$I$48))*((H27)^($I$48-1))	=EXP(-((H27/$I$49)^$I$48))		
28	=(+$I$48/($I$49^$I$48))*((H28)^($I$48-1))	=EXP(-((H28/$I$49)^$I$48))		
29	=(+$I$48/($I$49^$I$48))*((H29)^($I$48-1))	=EXP(-((H29/$I$49)^$I$48))		
30	=(+$I$48/($I$49^$I$48))*((H30)^($I$48-1))	=EXP(-((H30/$I$49)^$I$48))		
31	=(+$I$48/($I$49^$I$48))*((H31)^($I$48-1))	=EXP(-((H31/$I$49)^$I$48))		
32	=(+$I$48/($I$49^$I$48))*((H32)^($I$48-1))	=EXP(-((H32/$I$49)^$I$48))		
33	=(+$I$48/($I$49^$I$48))*((H33)^($I$48-1))	=EXP(-((H33/$I$49)^$I$48))		
34	=(+$I$48/($I$49^$I$48))*((H34)^($I$48-1))	=EXP(-((H34/$I$49)^$I$48))		
35	=(+$I$48/($I$49^$I$48))*((H35)^($I$48-1))	=EXP(-((H35/$I$49)^$I$48))		
36	=(+$I$48/($I$49^$I$48))*((H36)^($I$48-1))	=EXP(-((H36/$I$49)^$I$48))		
37	=(+$I$48/($I$49^$I$48))*((H37)^($I$48-1))	=EXP(-((H37/$I$49)^$I$48))		
38	=(+$I$48/($I$49^$I$48))*((H38)^($I$48-1))	=EXP(-((H38/$I$49)^$I$48))		
39	=(+$I$48/($I$49^$I$48))*((H39)^($I$48-1))	=EXP(-((H39/$I$49)^$I$48))		
40	=(+$I$48/($I$49^$I$48))*((H40)^($I$48-1))	=EXP(-((H40/$I$49)^$I$48))		
41	=(+$I$48/($I$49^$I$48))*((H41)^($I$48-1))	=EXP(-((H41/$I$49)^$I$48))		
42	=(+$I$48/($I$49^$I$48))*((H42)^($I$48-1))	=EXP(-((H42/$I$49)^$I$48))		
43	=(+$I$48/($I$49^$I$48))*((H43)^($I$48-1))	=EXP(-((H43/$I$49)^$I$48))		
44	=(+$I$48/($I$49^$I$48))*((H44)^($I$48-1))	=EXP(-((H44/$I$49)^$I$48))		
45				
46		VALUE	GAMMA	
47	1 + 1/BETA	=1+(1/I48)	0.93969	
48	1 + 2/BETA	=1+(2/I48)	=(1-L48)*0.90012	
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Table 14. Formulas used in Weibull calculations (All failure times)

	O	P	Q
1	Failure	300 Hrs	1500 Hrs
2	Hrs	Prob	Prob
3	50	=+EXP(-((300/$I$49)^$I$48-($O3/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O3/$I$49)^$I$48))
4	100	=+EXP(-((300/$I$49)^$I$48-($O4/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O4/$I$49)^$I$48))
5	150	=+EXP(-((300/$I$49)^$I$48-($O5/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O5/$I$49)^$I$48))
6	200	=+EXP(-((300/$I$49)^$I$48-($O6/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O6/$I$49)^$I$48))
7	250	=+EXP(-((300/$I$49)^$I$48-($O7/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O7/$I$49)^$I$48))
8	300	=+EXP(-((300/$I$49)^$I$48-($O8/$I$49)^$I$48))	=+EXP(-((1500/$I$49)^$I$48-($O8/$I$49)^$I$48))
9	350		=+EXP(-((1500/$I$49)^$I$48-($O9/$I$49)^$I$48))
10	400		=+EXP(-((1500/$I$49)^$I$48-($O10/$I$49)^$I$48))
11	450		=+EXP(-((1500/$I$49)^$I$48-($O11/$I$49)^$I$48))
12	500		=+EXP(-((1500/$I$49)^$I$48-($O12/$I$49)^$I$48))
13	550		=+EXP(-((1500/$I$49)^$I$48-($O13/$I$49)^$I$48))
14	600		=+EXP(-((1500/$I$49)^$I$48-($O14/$I$49)^$I$48))
15	650		=+EXP(-((1500/$I$49)^$I$48-($O15/$I$49)^$I$48))
16	700		=+EXP(-((1500/$I$49)^$I$48-($O16/$I$49)^$I$48))
17	750		=+EXP(-((1500/$I$49)^$I$48-($O17/$I$49)^$I$48))
18	800		=+EXP(-((1500/$I$49)^$I$48-($O18/$I$49)^$I$48))
19	850		=+EXP(-((1500/$I$49)^$I$48-($O19/$I$49)^$I$48))
20	900		=+EXP(-((1500/$I$49)^$I$48-($O20/$I$49)^$I$48))
21	950		=+EXP(-((1500/$I$49)^$I$48-($O21/$I$49)^$I$48))
22	1000		=+EXP(-((1500/$I$49)^$I$48-($O22/$I$49)^$I$48))
23	1050		=+EXP(-((1500/$I$49)^$I$48-($O23/$I$49)^$I$48))
24	1100		=+EXP(-((1500/$I$49)^$I$48-($O24/$I$49)^$I$48))
25	1150		=+EXP(-((1500/$I$49)^$I$48-($O25/$I$49)^$I$48))
26	1200		=+EXP(-((1500/$I$49)^$I$48-($O26/$I$49)^$I$48))
27	1250		=+EXP(-((1500/$I$49)^$I$48-($O27/$I$49)^$I$48))
28	1300		=+EXP(-((1500/$I$49)^$I$48-($O28/$I$49)^$I$48))
29	1350		=+EXP(-((1500/$I$49)^$I$48-($O29/$I$49)^$I$48))
30	1400		=+EXP(-((1500/$I$49)^$I$48-($O30/$I$49)^$I$48))
31	1450		=+EXP(-((1500/$I$49)^$I$48-($O31/$I$49)^$I$48))
32	1500		=+EXP(-((1500/$I$49)^$I$48-($O32/$I$49)^$I$48))
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Table 14. Formulas used in Weibull calculations (All failure times)

n	Γ (n)	n	Γ (n)	n	Γ (n)	n	Γ (n)
1.00	1.00000	1.25	.90640	1.50	.88623	1.75	.91906
1.01	.99433	1.26	.90440	1.51	.88659	1.76	.92137
1.02	.98884	1.27	.90250	1.52	.88704	1.77	.92376
1.03	.98355	1.28	.90072	1.53	.88757	1.78	.92623
1.04	.97844	1.29	.89904	1.54	.88818	1.79	.92877
1.05	.97350	1.30	.89747	1.55	.88887	1.80	.93138
1.06	.96874	1.31	.89600	1.56	.88964	1.81	93408
1.07	.96415	1.32	.89464	1.57	.89049	1.82	.93685
1.08	.95973	1.33	.89338	1.58	.89142	1.83	.93969
1.09	.95546	1.34	.89222	1.59	.89243	1.84	.94261
1.10	.95135	1.35	.89115	1.60	.89352	1.85	.94561
1.11	.94739	1.36	.89018	1.61	.89468	1.86	.94869
1.12	.94359	1.37	.88931	1.62	.89592	1.87	.95184
1.13	.93993	1.38	.88854	1.63	.89724	1.88	.95507
1.14	.93642	1.39	.88785	1.64	.89864	1.89	.95838
1.15	.93304	1.40	.88726	1.65	.90012	1.90	.96177
1.16	.92980	1.41	.88676	1.66	.90167	1.91	.96523
1.17	.92760	1.42	.88636	1.67	.90330	1.92	.96878
1.18	.92373	1.43	.88604	1.68	.90500	1.93	.97240
1.19	.92088	1.44	.88580	1.69	.90678	1.94	.97610
1.20	.91817	1.45	.88565	1.70	.90864	1.95	.97988
1.21	.91558	1.46	.88560	1.71	.91057	1.96	.98374
1.22	.91311	1.47	.88563	1.72	.91258	1.97	.98768
1.23	.91075	1.48	.88575	1.73	.91466	1.98	.99171
1.24	.90852	1.49	.88595	1.74	.91683	1.99	.99581
						2.00	1.00000

Values of $\Gamma(n) = \int_0^\infty \exp^{-x} x^{n-1}\, dx;\ \Gamma(n+1) = n\Gamma(n)$

Table 15. GAMMA Function

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